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ANIMAL FLIGHT.

ANIMAL FLIGHT

A RECORD OF OBSERVATION.

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“ In the system of Copernicus there are many and grave difficulties : for the three-fold motion with which he encumbers the earth is a serious inconvenience ; and the separation of the sun from the planets, with which he has so many affections in common, is likewise a harsh step ; and the introduction of so many immovable bodies in nature, as when he makes the sun and stars immovable, the bodies which are peculiarly lucid and radiant, and his making the moon adhere to the earth in a sort of epicycle, and some other things which he assumes, are proceedings which mark a man who thinks nothing of introducing fictions of any kind into nature, provided his calculations turn out well.”—LORD BACON.

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PREFACE.

This book contains a record of observations that I have carried out on different kinds of flying animals, often under exceptionally favourable conditions. Its chief interest will, I think, be found in the facts relating to soaring flight, a subject which hitherto has not received the detailed treatment that it deserves.

It is unfortunate that those best qualified to form an opinion as to the nature of the phenomenon have, as a rule, had little or no opportunities of studying the facts at first hand. Such authorities have, in some cases, published accounts of soaring flight which have consisted entirely of explanation. Others have related a few of the facts with more or less tentative explanations. The present book will be found to contain the facts of the case with no explanation at all.

This can scarcely be regarded as a satisfactory example of division of labour. History furnishes examples of great authorities who, in expressing an opinion on subjects more important than soaring flight, have been handicapped by insufficient acquaintance with the facts of the case. Any authority who wishes to express an opinion on soaring flight in future may protect himself from such a mischance by buying—and reading—this book. In it he will find described every visible movement of the soaring bird. Even minute symptoms of instability, that in certain cases occur but rarely, and that can only be seen after prolonged practice in observation, will be found to have some

PREFACE (continued).

mention. For the most part I have used non-technical language, and what I have written, being essentially a description of facts, should be easily comprehensible to the general reader.

The late Professor Roy, of Cambridge, to whose influence and help in my student days I look back with gratitude and affection, was the first to tell me that there was a problem to be solved in connection with soaring flight. In his article on "Flight," in Newton's "Dictionary of Birds," he clearly states that explanations of soaring flight hitherto brought forward are insufficient, and points out the need for further information on the subject.

Other observers have used similar expressions. Sir C. Wyville Thomson in describing the flight of the albatross says: "Notwithstanding all that we know or think we know about the mechanics of flight, to the last I felt inclined to protest that for so heavy a bird to support itself motionless in the air, and perform its vigorous evolutions without a perceptible movement of the wings, was simply impossible by any mechanical means of which we have the least conception." (*The Atlantic*, Vol. II., page 146.) Sir Guilford Molesworth, after describing the soaring flight of eagles in the Himalaya mountains in "an enclosed valley in which there was not a breath of air," asserts that "many theories have been advanced to account for these phenomena, but they have all been miserably insufficient. I asked Lord Kelvin if he could explain them, but he replied: 'That which puzzled Solomon puzzles me also.'" (*Indian and Eastern Engineer*, Vol. XXXIII., page 19.) Such information as this book contains will

PREFACE (continued).

be found both to justify these opinions and to indicate a wide field of research that promises to lead to valuable results in connection with our knowledge of the nature of the air and of its store of energy.

Part of the contents of this book have already been published in the pages of *Flight* in a series of weekly articles that appeared from August to December, 1911. I have to express my obligations to the editor of *Flight* for his assistance in their first publication and for his permission to make use of them in preparing this book. But the greater part of the facts now brought forward have not previously appeared in print. The chapters on the flight of flying fishes, the flight of seagulls, on wind soarability, on soarability in stormy winds, on the very curious colour phenomena associated with soaring flight, on the relative efficiency of different wing forms, and on the flight of dragon-flies, consist for the most part of information now published for the first time.

I must express my thanks to the Advisory Committee for Aeronautics for having kindly given me information on certain points that I submitted to them. I am indebted to the authorities of the Bombay Natural History Society for having allowed me to examine a number of birds in their collection. Mr. W. Jesse has helped me with his ornithological knowledge. Major H. R. Cooke, R.A., accompanied me to Jharna Nullah, and, at my request, published an account of his observations there made confirmatory of my own. (*Flight*, 20th January, 1912, page 71.) Mr. Somers Somerset aided me in certain observations on flying fishes in the Red Sea. I must express my thanks to Captain Palmer, R.N.R., for giving me certain meteorological data during

PREFACE (*continued*).

a voyage from Marseilles to Bombay on the P. and O. ss. *Arabia*. Mr. G. E. Nicholls, Lecturer on Biology at the Agra College, has helped me in certain dissections, and I have to thank him especially for a drawing of the muscles of the wing of a flying fish that appears in Chapter XIII. Lastly, I am greatly indebted to Major Dickinson, I.M.S., F.I.C., for very valuable help in correction of the proofs.

E. H. HANKIN.

Agra, India, January, 1913.

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CHAPTER I.

INTRODUCTION.

The atmosphere consists of a mixture of gases, which, under the conditions existing in the air, is, so far as is known, of a low degree of chemical activity.

Nevertheless, the air is the seat of many and varied manifestations of energy whose nature and origin are, at present, beyond our ken. A puff of wind, a thunder-storm, a shower of rain, are examples of phenomena of whose exact causation no satisfying explanation has, as yet, been given. If they were not so familiar they would be regarded as the most surprising and wonderful of our experiences.

The study of natural flight is of importance in that it promises to give us knowledge, perhaps not otherwise obtainable, of the secret of the air, its store of energy, and its ceaseless change. Of the different kinds of animal flight, the soaring flight of the larger birds is, with little doubt, the most important from this point of view.

About twenty-three miles from Agra the rocky hill of Futteypur-Sikri rises steeply from the plain. I have there observed when a wind is blowing, and the weather is fine, soaring birds gliding at their ease over the crest of the hill, taking advantage of the ascending current of air. But I have been at Futteypur-Sikri on other occasions when even blowing smoke from a cigar failed to reveal the presence of wind. Despite this apparent calm, the birds were seen making almost the same astounding movements of soaring flight as if an ascending current

were demonstrably present, always with absence of visible effort, and only making occasional directive movements that are as difficult to understand as to recognise.

This is an example of what is almost a general rule in the study of soaring flight in a tropical country. Superficial observation reveals facts easy to explain. Continued observation reveals facts whose cause is at present beyond our comprehension. In such a case, what is required is not theorising, but observation and measurement.

Prevalent views of the nature of soaring flight in tropical countries are based on observations of so casual and imperfect a nature that they may, in many cases, be fairly described as travellers' tales.

The knowledge of the facts of the case being insufficient, it is not surprising if various worthless theories have been brought forward. Those who have not seen soaring flight in a hot climate are apt to suppose that the poising of a kestrel hawk on the windward side of a haystack exemplifies all the forces and principles involved. Others, who have seen soaring flight, have, in certain cases, supposed that it is due to a sort of suspension of the ordinary laws of nature, if the phrase may be allowed. The following example may be quoted :

A writer who signs himself A. O. H. watched vultures in Simla at a height of about 7,000ft. in the Himalaya Mountains.¹ He states that these birds start their flight in summer between six and seven o'clock in the morning, but in winter not till nearly nine o'clock. Their usual speed of flight he estimates to be from twelve to fifteen miles an hour, the lowest speed of

¹ "On the Flight of Birds," *Stray Feathers*, Vol. X., No. 4, p. 248, July, 1882.

gliding to be seven to eight miles an hour, and the highest twenty-six to twenty-seven miles an hour. The species observed was *Gyps himalayensis*, a vulture of 9ft. span. When gliding in a straight line for miles the only movement shown by this vulture was an occasional and gradual "shift" of the tail. He says that crows can soar, rising in circles without flapping, but that they do so only when the air is quite calm. He states that soaring flight is due to "levitation." This is a miracle or conjuring trick in virtue of which a man can remain unsupported in the air. He says that it consists in "so altering the magnetic polarity of the physical frame that in lieu of being attracted it is repelled by the earth." This power is achieved by "living an absolutely pure life and intense religious concentration." Birds are endowed with this power, apart from such mental exercises, unless, it may be suggested, the hill crow finds it helpful to indulge in irreligious sentiments when trying to descend to earth without the help of gravity.

Others, having a clearer idea of causation, have attempted to show mathematically how soaring flight could be explained if the wind has a certain upward trend, or if the air is subject to horizontal pulsations.¹ Such theories have been put forward as possibilities. They are admittedly not based on facts of observation, although, by some, they have been mistaken for established doctrines. But, as will be seen, the study of soaring flight brings us face to face with an extremely complicated series of phenomena, and there is room for doubt how far these simple mathematical conceptions carry us towards an explanation.

¹ See Lanchester, "Aerial Flight," Vol. II., Aerodnetics (Constable and Co., London, 1910).

I propose in this book to describe the actual facts of soaring flight as they have come under my observation. To do so, it will be necessary to describe the adjustments used by soaring birds for steering, for checking speed, and for various other flight manœuvres. To understand these phenomena, and to support my inferences as to their nature, I have found it necessary to extend my observations to bats, flying fishes, and insects.

If soaring flight cannot be described without a comprehension of flight manœuvres, still more these manœuvres cannot be described without some knowledge of soaring flight. Hence, for the sake of intelligibility, elementary descriptions of each subject must precede the more detailed descriptions found in later chapters.

As this book consists in great part of a description of the facts relating to various kinds of flight, it is necessary that the reader should have some assurance that he is reading an actual description of the facts as they exist, untinged by my opinion as to the meaning of the facts. Hence, disregarding the requirements of literary style or finish, I have inserted numerous extracts from my diary. It is inevitable that, to the student, these descriptions of actual facts of observation will be more valuable than inferences and conclusions. Especially in the case of difficult observations, such as many of those about to be described, it is not sufficient for the observer to observe, and later on to write down his opinion. It is necessary that he should write down at the time what he sees, without any reference to any preconceived ideas of what is possible or what is impossible. It may easily happen that an observer is correct in his observation and mistaken in his inference.

My opportunities of observation have been good. Frequently I have watched vultures and adjutant birds of 7ft. to 10ft. span gliding within a few feet of where I was standing. Despite these advantages, it has often taken me weeks of practice before I could see and realise the meaning of some particular wing adjustment. Having recognised a certain adjustment in the flight of one species of bird, it has frequently taken me further weeks of practice before I could see it in a bird of another species.

The following is a brief description of the species of birds on which most of my observations have been made:

(1.) The "Cheel" (*Milvus govinda*). Span, 4ft. Loading, .55 lb. per square foot.¹

The cheel or pariah kite is perhaps the commonest bird in Indian towns and cantonments. If observed during the heat of the day, and especially in a varying light wind, its movements appear to have nothing in common with the majestic circling flight of the larger soaring birds. As it glides in any direction, skimming over the tops of the trees or houses, its wings appear to yield haphazard to every puff of wind. The tail at one moment is furled, at another expanded like a fan, and frequently shows slight and sudden rotations to and fro round its long axis. Slight depressions of one or both wings follow one another so suddenly, and so often without visible effect on the direction of flight,

¹ By "loading" is meant the weight lifted per unit of supporting area. If the total area of the two wings taken together were found to be 10 sq. ft., and if the weight of the bird were 20 lbs., then the loading would be 2 lbs. per square foot. In most soaring birds the tail is relatively small, and is habitually kept furled during gliding flight. In such birds, the wing area alone should be taken into consideration in calculating the loading. Certain of the smaller birds, such as the dove and the hill crow, habitually glide with the tail widely expanded. In these cases the tail plays some part in support. The bird is lifted on a tripod consisting of the two wings and the tail. In calculating the loading of such birds, it would therefore be appropriate to include the tail area besides that of the wings.

that it may well appear a hopeless task to discover their nature and object.

Usually the cheel flies with its tail not expanded like a fan, but furled. The hinder end of the furled tail appears forked. This character serves to distinguish the cheel when flying from the Indian Tawny Eagle, the end of whose tail appears rounded. When seen flying from a distance of one or two miles, the cheel and the crow may be difficult to distinguish, although the latter is a smaller bird. But one distinction can easily be made under any conditions. The crow flaps continually. In Agra it only glides when losing height and, as a rule, before settling. The cheel resembles other soaring birds in that it never flaps for indefinite distances, and periods of flapping are always alternated with periods of gliding. The term "flap-gliding" may be used for this form of flight.

(2.) The "Scavenger" or "White Scavenger Vulture" (*Neophron gingianus*). Span, 5ft. Loading, .87 lb. per square foot.

This bird when settled appears of a dirty white colour, with yellow beak, and has a singularly untidy appearance. When flying the wings appear white with black wing-tips and black hind margins. It often flies in company with cheels at low levels. A closely allied species (*Neophron percnopterus*) is known as the Egyptian Vulture or Pharaoh's Chicken. Wing adjustments are difficult to see in the scavenger and I have learnt but little from its flight.

(3.) The "Common Vulture" or "White Backed Vulture" (*Pseudogyps bengalensis*). Span, 7ft. Loading, 1.13 lb. per square foot.

This bird is a typical vulture in appearance. Its back and rump are white. The rest of the body is black above and brownish-black below. When in flight the underside of the wing is seen to have black wing-tips and a black hind margin. A large area of the central part of the underside of the wing is white, but appears yellow under ordinary conditions of flight. This description applies to the adult bird. The white colour is absent from the young.

At Jharna Nullah, a few miles from Agra, is a factory of dried buffalo meat, where these birds exist in thousands, acting as welcome and efficient scavengers. Usually a few of them may be seen gliding overhead, at heights of from 500 to 1,000 metres, anywhere in Agra. At the time of starting their morning flight these birds usually cease flapping at a height of from 10 to 20 metres above the ground. If they start during the heat of the day, when, as observation shows, the air has become more suitable for soaring flight, they may cease flapping within 4 or 5 metres of the ground. They then glide in circles, with complete absence of propulsive movement, and usually reach a height of 800 metres or more.

The soaring flight of these birds is puzzling, not from the excess of directive movements, as in the case of the cheel, but from their apparent absence. Frequently circle after circle may be watched without any trace of directive movements of the wings or tail being detected.

(4.) The "Black Vulture" (*Otogyys calvus*). Span, 6½ft. Loading, 1.23 lb. per square foot.

This bird is comparatively rare. Usually only three or four specimens can be seen at a time at Jharna Nullah. Black predominates in its colouring, but the head and legs have a red or orange-red colour. The quill feathers of its wing-tips, when bent up by air pressure, make a longer and more graceful curve than do the wing-tip feathers of other kinds of vulture. This feature enables the bird to be identified even at a distance too great for recognition by any other character.

(5.) The "Adjutant" (*Leptoptilus dubius*) is a large species of stork. Its span is usually a little over 9ft. One that I had in captivity for some months had a span of nearly 11ft. The loading is 1.54 lb. per square foot of wing area.

The beak is nearly 1ft. long. The body is white underneath. When in flight the wings appear dark grey. Their base is white. Another species of stork is occasionally seen that resembles the adjutant when in flight, but has the base of the wings black. A pouch hanging down from the underside of the neck of the adjutant is usually regarded as a conspicuous character of this bird. But this pouch varies greatly in size. It reaches its maximum dimensions, which may be 16in. long and 3in. or more thick, a few weeks before the breeding season. At other times of the year the pouch is only 1in. or 2in. long and quite inconspicuous. In view of the clumsy shape of the bird, its large head, long neck, and the presence of this pouch, it is difficult to imagine that it has a good "gliding angle." Nevertheless, it is an adept at soaring flight. It is a striking sight to see this bird gliding at a speed of perhaps 30 miles an hour, urged on by the unknown force of

soarability, with its long pendant pouch swaying to and fro in the wind, and showing no trace of the pressure that the air must be exerting on the wings a few inches away.

The adjutant is a temporary resident in Agra, as a rule. During the monsoon season I have counted as many as 115 at Jharna Nullah. After the monsoon, in October, most of these birds emigrate, only a few individuals remaining here during the cold weather.

The adjutant may frequently be seen stealing food from vultures. Its long, straight beak is not adapted for tearing off pieces from a carcase. When a number of vultures are at work, two or three adjutants usually stand behind them. As soon as a piece of meat has been torn off, an adjutant steps forward and takes it. The vultures make no protest.

These five different kinds of birds, on which most of my observations have been made, are easy to recognise whilst in flight. In addition, I have made many observations on different species of brown vultures, and on various kinds of eagles, many of which are difficult to distinguish while on the wing, even by a trained ornithologist.

The country surrounding Agra is flat. The climate is dry, except in the monsoon season (July to September), when it is damp and hot. Occasionally a few showers occur during the cold weather, when the air may be damp and cold. I have also had opportunities for studying the flight of vultures at Naini Tal, in the Himalaya Mountains, at a height of from 6,000ft. to 8,000ft. above sea level.

If the bird is near enough the most satisfactory observations are, in my experience, made with the naked eye. Otherwise a binocular must be used. A short-bodied prism binocular is not suitable for the purpose. The long-bodied direct vision instrument is preferable, as the length of the body facilitates rapid aiming. A large field of view is objectionable when working under the glare of a tropical sun. That the eyepiece should be recessed is of advantage, as this construction also aids rapid aiming at the object.

I have usually used a "Souchier telemeter." This is a binocular field-glass having an arrangement by which a crystal of Iceland spar can be slid over each eyepiece. When the Iceland spar is in position, the image of the object looked at appears double. The further away the object, the further apart do the two images appear. Hence, if the size of the object is known, an estimate of its distance can be made. In my instrument, the overlap of the two images is 5in. when the object is 100 metres distant. If the overlap of the two images is found to be 10in., then the object must be 200 metres away, and so on. For instance, suppose we look at a bird whose wing is known to be 10in. wide. Suppose the bird is overhead, and is so placed that one image appears just behind the other, then, if the images of the two wings just clear one another, the height at which the bird is flying is 200 metres. Nearly every specimen of the common vulture that I have examined is of 84in. or 85in. span. Supposing a vulture is overhead, and is so placed that, when viewed in the telemeter, the two images are seen side by side; and supposing also that the wing-tip of one image touches the

wing-tip of the other, then, since $85 = 17 \times 5$, the height of the bird above the earth must be 1,700 metres.

The following table gives the greatest heights at which I have seen vultures or adjutants soaring in different months of the year. There is every reason for believing that these heights are attained by gliding unaided by flapping, except for a few metres when leaving the ground. The birds of heaviest loading are usually those seen at greatest heights :

	Metres.			
January	2,000			
February	1,700			
March	2,000, 1,800			
April	1,600, 1,600			
May	—			
June	—			
July	1,000, 1,000			
August	700, 1,000			
September	1,200, 1,900			
October	1,200, 1,600, 2,000			
November	1,700, 1,700, 1,800			
December	700, 800			

When at heights of 1,500 to 2,000 metres birds are very difficult to see. Either they may become visible owing to their becoming canted up (when circling) and the sun then striking the underside of the wings, or they may be seen on a background of brightly illuminated white cloud.

The above figures amply prove that soaring flight, in Agra, is not due to ascending currents reflected upwards from the walls of trees or buildings. If soaring flight in Agra is due to ascending currents, these currents must have some other origin. In temperate climates, soaring birds are known to look for, and use, ascending currents reflected up from a cliff, a row of trees, etc. In Agra, vultures commonly take pains to avoid such

upward currents. On one occasion I saw some vultures apparently soaring in the ascending current reflected upwards from the walls of the Agra Fort. Recognising this to be quite unusual, I went in my motor to investigate. I found that the appearance was illusory. My point of observation, the position of the windward side of the Fort, and the group of birds, had been in a straight line, which line was at right angles to the wind direction. The vultures were not over the Fort, but some distance beyond it. On one exceptional occasion, however, I have seen vultures remaining for a few minutes apparently within the influence of the ascending current in question.¹ Cheels, on the other hand, do frequently take advantage of the ascending current at times when the air is not "soarable" or not fully soarable, as will be described in a future chapter. During dust-storms, numbers of cheels may be seen gliding near my house. This house is on a small hill (formed from an old brick kiln), and during a strong wind an ascending current is reflected up from it. In dust-storms, with soarable air, cheels carefully avoid this ascending current.

It will be shown in later chapters that the form of soaring flight that requires the greatest amount of energy is the high speed flight that I have designated "flex-gliding." Different kinds of birds commonly flex-glide at different heights. These are as follows:

For the cheel	..	..	..	80 metres
,, scavenger	..	..	..	120 ,,
,, black vulture	..	..	..	220 ,,
,, common vulture	..	..	..	400 ,,
,, adjutant	..	..	..	800 ,,

¹ In Chapter XX. a case is described in which vultures took advantage of the ascending current on the windward side of the hill of Futteypur-Sikri whenever the air was unsoarable. It may be noted that this ascending current is of much greater extent than any ascending currents likely to be reflected up from trees or buildings in Agra.

This is a rule to which there are very numerous exceptions. Cheels, for instance, may be seen flex-gliding at any height up to 2,000 metres. The height at which the common vulture flex-glides is also very variable. But in fine weather, and in a light wind, birds of each kind are not often seen flex-gliding below the heights stated. It will be noted that the heights are inversely as the weights, with the exception of the black vulture, which has a slightly higher loading than the common vulture. Owing to its habit of venturing to so low a level, the black vulture often finds itself in air in which its flight is hindered. It then shows lateral instability, and may be reduced to flapping. The heaviest bird, the adjutant, on rare occasions may be seen flex-gliding at 300 or 400 metres height. Usually it prefers a higher level. Recently (July, 1912) I saw an adjutant flex-gliding in the direction of Jharna Nullah at a height of 1,100 metres. While so doing it travelled in an apparently perfectly straight line. It was just under the level of an advancing rain cloud. Often for considerable distances it was enveloped in the cloud. Had it glided at a few feet lower level it would have been able to see where it was going. Other facts to be mentioned in later chapters will be found to agree with the suggestion implied in the above facts about flex-gliding, namely, that, as a rule, the air is more soarable at higher levels.

It has been suggested that the changes in wind velocity as shown by an anemometer in some way supply energy for soaring flight. But these changes in wind velocity are greatest at ground level, and, so far as is known, less at a height. That is to say, where

there is more soarability there is less wind variation, and *vice versa*. Thus the facts at present known appear to contradict the idea that changes in wind velocity are the cause of soarability. But it is a matter that deserves further investigation, especially as to whether a registering anemometer shows any difference between the soarable and unsoarable winds described in a later chapter.

Thus at the outset we find a difference between true soaring flight, as observed inland in tropical climates, and what may be described as false soaring flight, frequently observed in temperate latitudes. In the latter case birds show skill in finding and using such currents. In the former case birds show skill in avoiding them.

In the table (given on a previous page) of observations of greatest heights attained, no records are given for the months of May and June. The chief reason for this is the fact that climatic conditions during those months are very unsuitable for observation. Owing to the closure of the Jharna Nullah Factory, during the hot season, very few vultures are to be seen. But another reason is the fact that, in warm weather, birds are frequently invisible, or can only be seen with difficulty when more than a few hundred metres above the earth. Some of the blueness of the sky seems to come between the bird and the observer. The bird appears to be of a faint bluish-grey colour on the background of blue sky. Under such conditions a large amount of dust is often floating in the air. It is possible that in some cases this has to do with the indistinctness of the appearance of the birds. But it cannot be the chief factor, as the air somewhat suddenly

becomes transparent late in the afternoon, and there is no reason for believing that the dust suddenly settles. It is possible that the comparative "opacity" is due to movements of small masses of air produced by the heat of the sun, and that these movements decrease as the power of the sun diminishes, thus rendering the air transparent. It is a matter of common observation that, at about this time, the air near the earth becomes unsuitable for soaring flight. The following extracts from my diary illustrate this point :

4th May, 1910. At 4.57 p.m.—Distant visibility began. A scavenger and some common vultures seen at 1,000 metres height.

4.59.—Two scavengers at low level flapping. Flapping flight at low level had not been previously observed.

23rd September, 1911. At 1.0 and 4.0.—Air too thick for observing.

4.5.—Low level flapping observed.

4.8.—Distant visibility. A cheel seen at 800 metres, and a vulture at 1,200 metres height.

The above extracts from my diary are examples of very numerous observations that I have made on this point. On the facts one may base the following argument: Movements of small masses of air cause what, for want of a better term, may be called opacity of the air. These movements cease late in the afternoon, and the air becomes transparent. Soarability at low levels ceases at the same time. Therefore soarability depends on the movements of small masses of air. But that it is premature to draw any such conclusion is shown by the following fact: If small clouds, especially cirro-cumulus clouds, are present, and the sun is shining, the air may be perfectly transparent all through the day, but is fully soarable and becomes unsoarable at low levels at the usual time late in the afternoon. That is to say, the facts now described show that if soarability

is due to movements of parts of the air, then these movements must be of a different nature from those that cause opacity, supposing that opacity is due to such a cause.

I have employed the words "soarable" and "soarability" as applied to the air. These words are necessary for purposes of description, and imply nothing as to the reason why sometimes the air can and sometimes cannot furnish the energy necessary for soaring flight. To speculate on the reason for the difference is at present premature.

CHAPTER II.

PRELIMINARY DESCRIPTION OF SOARING FLIGHT.

When I first commenced the study of soaring flight, it appeared to me that there was little hope of learning much by watching the movements of the birds when they had reached a great height. Obviously at any given moment a bird may be trying to gain height, or to remain where it is, or to descend. When, on the other hand, the birds are near the ground, there is more probability that at any given moment they are trying to gain height. From this consideration it occurred to me that it would be worth while to observe soaring birds as they started in the early morning.

My observations soon revealed the unexpected fact that in fine weather there is a definite time, varying from day to day, at which soaring commences. For instance, if on a particular day in October I saw a cheel soaring for the first time at 8.30 a.m., then within a few minutes at least a dozen cheels would be seen circling in the air. My post of observation was on the roof of my house, from which position I have a view of several square miles of country, including the town and cantonment of Agra. Apparently within two or three minutes, as a rule, the air becomes capable of soaring flight over the whole area of Agra city. Soaring flight nearly always, in fine weather, commences over the trees and gardens of the cantonments a few minutes later than it begins over the houses of the city.

When the fact is thus baldly stated another possibility suggests itself, namely, that cheels have an instinct that teaches them not to indulge in soaring flight before 8.30. A further acquaintance with the facts definitely excludes this possibility. For instance, if in the early morning a gun is fired near the Jharna Nullah Factory, cheels and vultures rise in flap-gliding flight, and in a minute or two settle. Supposing a gun is fired a little later, when the air has just become soarable for cheels, those that have not yet started will then rise into the air and remain there circling. The vultures that are disturbed will soon return to earth. Usually about half an hour to an hour later the air has become soarable for vultures. On then firing a gun, any vulture that has not yet started will rise into the air and circle. As will be further described in a later chapter, the different species of soaring birds start at fairly regular intervals after the cheel. The birds always start exactly in the order of their loading. The heavier the bird, the later is the time. Further, I shall have to describe different forms of soaring flight, and shall show that they begin to be used at different times after the commencement of circling. Cheels not infrequently are seen in flap-gliding flight immediately after sunrise, that is to say, a couple of hours before the air is capable of supporting them in soaring flight. These different facts taken together leave no room for doubt that the air in the early morning is unsuitable for soaring flight, and that it gets more and more suitable for such flight as the day goes on.

Evidence bearing on the question of the nature of the changes in the air that make it soarable will be

brought forward in later chapters. But I may state here that my observations make it certain that this change has nothing to do with any strengthening of the force of the wind. Soaring often commences at a time when the early morning wind, if there has been one, has just died away, and when such wind as exists is so light that it is difficult to determine its direction. The usual day wind in fine weather only commences, as a rule, some time after soarability for cheels has been established.

The time of commencement of circling of cheels is usually at about 9.30 a.m. during December. As the weather gets warmer the time gets earlier month by month till in June cheels are able to circle a little after 7 a.m. From June onwards the time gradually gets later.

The above description applies to the phenomenon observed in fine weather. In disturbed weather, either soarability may be absent or it may develop unusually early. In such cases evidence is easily obtained that the soarability is somehow connected with the presence of wind. A description of this "wind soarability" will be found in a later chapter.

The following extracts from my diary illustrate some of the facts now under discussion. My house, from the roof of which these observations were made, is situated in the cantonment :

25th November, 1909.—From 8.30 onwards the wind was light and unable to move the leaves of the trees near, but at 9.35 the leaves were occasionally in motion.

8.44 to 9.16.—Fifteen cheels observed at intervals either flap-gliding or flap-circling.¹

¹ By "circling" I mean that the bird glides in circles without flapping. By "flap-circling" I propose to designate gliding in circles with occasional periods of flapping.

9.17.—Two cheels flap-circling, and two circling near house.

9.18.—Two cheels circling near Infantry Barracks (one and a half miles distant).

9.35.—Many cheels circling in different directions.

18th May, 1910. 7.0.—Wind west, now dropping. Leaves slightly moving.

7.40.—A cheel circling near. It showed dihedrally-up¹ position of wings. It glided down at 7.41.

7.43.—A cheel circled near and settled.

7.45.—No cheels up in city.

7.52.—One cheel circled in city and glided down.

7.55.—Two cheels circling at high level in civil lines (beyond city), one in Chipitola, and two circling in other parts of city. One in Chamara-pura (a village threequarters of a mile distant).

7.58.—One cheel circling over Company Garden and one near.

8.1.—Seven cheels circling over city.

8.4.—Five cheels circling near. Wind rising.

8.15.—Scavenger circling near.

I now propose to give a preliminary description of circling flight.

In the following description I shall make use of two expressions that will be familiar to yachtsmen: By "up-wind" I mean a direction against the wind or going to windward; by the term "down-wind" I mean a direction with the wind or going to leeward. I use the term "circle" and "circling" as a matter of convenience, although, as will be shown later, the tracks described by circling birds are not perfect circles.

The cheel at the commencement of circling flight in the morning shows the same steady, and so to speak, careful flight as do the heavier birds later in the day. The wings appear to remain in the same plane, and the use of balancing or directive movements can only with difficulty be discovered.

The cheel rises into the air by flapping flight to a height of a few feet above the tree tops. Then it commences to glide in circles. Sometimes at first these

¹ Two straight lines when they meet make an angle. Two flat surfaces when they meet make a "dihedral angle." The wings of birds may make with one another dihedral angles, which may be either "up" or "down," as shown in fig. 6.

circles are described partly by gliding and partly by flapping. The flapping usually occurs on the up-wind side of the circle. But the bird will be seen, either immediately or after a short interval, to be circling without flapping. In spite of the absence of propulsive effort the bird gains height. The gain of height is usually on the up-wind or windward sides of the track.

In the case of vultures, at the commencement of their circling, flapping may occur at any part of the circle. In one circle there may be four or five periods of flapping. But when the flapping ceases the gain in height will be seen to be mainly on the up-wind and windward sides of the circle, as in the case of cheels.

This gain in height on the windward and up-wind parts of the circle is the more surprising in that the cheel all the time is drifting to leeward. Each circle described is a few feet to leeward of its predecessor. More than once, when the wind was light and variable, I have discovered a change in its direction by observing the position of gain of height of a circling cheel, and proved the truth of the information thus obtained by seeing the direction of some smoke. Capt. S. Hutcheson, of the 3rd Brahmans, informs me that he has made the same observation of gain in height in soaring birds while going to windward, both in South Africa and in the Himalayas.

But this windward gain of height is not a constant phenomenon. Sometimes there is a gain of height on the leeward side of the circle; sometimes height is gained on the down-wind side. Rarely gain in height appears to occur almost equally all round the circle.

The following extract from my diary is an example of leeward gain of height :

December 24th, 1909.—In the morning the sky was clouded over. There was a light east wind. The sun came out at 10.30, and soaring commenced at 10.35. At 1.30 I was standing on the top of the gateway of the mosque at Futtepur-Sikri. The sun was shining. The wind was from the east and very light ; its direction was shown by smoke from a fire on the top of the ridge below me. The column of smoke was inclined over towards the west, and showed slow but distinct movement. Also occasionally I could feel the movement of the air. Some cheels, a white scavenger vulture, and a common vulture were soaring at a lower level than where I was standing and at about 100 yards distance. The vulture was seen to gain height both at the windward and at the leeward sides of the circle.

When there is gain of height on both the windward and leeward sides, there may be a loss of height between the two positions of gain, that is to say during the up-wind and down-wind parts of the circle. For instance, in the case of a vulture circling overhead in the afternoon in a westerly wind I have observed that the sun illuminated the underside of the wings at the commencement of the down-wind side of the track, proving that at that moment the bird was gliding downwards.

Further observations have shown that speed increases at the beginning of the down-wind side of the circle in such cases. The above case of the sun illuminating the underside of the wings at this point is an indication of a short dive, that is to say that the bird was gliding downwards in order to get up speed.

A noteworthy fact about the early morning circling of cheels and the circling of other birds later in the day is its slowness and regularity. Whenever I have had an opportunity of measuring the size of circles described by cheels, I have found them to be about 12 metres in diameter. The circles described by vultures are generally about 40 or 50 metres in diameter.

Cheels take 7 to 9 seconds, as a rule, to complete a circle. If a succession of circles are timed with a stop-watch, the period in the case of cheels often will be found not to vary by more than one-fifth of a second. The larger birds usually circle in from 13 to 16 seconds.

It has been suggested that soaring flight is due to the bird having skill in searching for and taking advantage of ascending currents and in avoiding descending currents. But circling flight is regular, therefore if the above suggestion is true, the ascending currents that subserve soaring flight must be distributed through the air with extraordinary regularity. The facts observed definitely exclude the idea that soaring flight in an inland tropical climate is due to the bird taking advantage of irregularly distributed ascending currents. Further facts supporting this argument will be brought forward in later chapters.

The following extracts from my diary may be quoted in support of the above statements:

October 31st, 1909.—On Tundla Road to leeward of Jharna Nullah. Wind west. A white scavenger vulture observed to make successive circles in 9, 8, 10, 9, 10, and 12 seconds. Then it made a circle of 7 seconds, and glided off in a straight line. A large vulture about 150 metres overhead made successive circles in 19, 10, 13, 15, 13, and 13 seconds. An eagle circled in 11, 14, and 15 seconds. A black vulture made successive circles in 17, 16, 15, and 20 seconds. While making these observations, a feather was seen floating in the air at 10.20, and three feathers at 10.30. They were at the height at which the birds were soaring. They drifted at about walking pace, and appeared to travel horizontally.

December 30th, 1909, at Jharna Nullah. 9.45.—Cheels began circling.

9.53.—White scavengers began circling with occasional flaps. They circled in 12 seconds. Cheels were circling in 9 seconds usually, but sometimes in 10 or 11 seconds. (My observations suggest that the rate is usually less in warmer weather.)

9.55.—Five columns of cheels were up.

10.22.—White scavengers circling without flapping.

10.24.—Large vultures had commenced soaring, and were circling in 13 seconds.

10.35.—A feather seen floating in the midst of a group of circling cheels. It was about 10 metres above my head. Observation with the telemeter failed to show either rise or fall. At this time cheels were circling in 11 seconds, and vultures in 13 to 16 seconds.

10.45.—First black vulture seen soaring.

11.15.—A black vulture seen making circles in 15 seconds.

In another kind of soaring flight about to be described the speed is distinctly faster than it is in circling. So far as I have observed, if soaring is difficult and the bird has to flap for part of the circle, the speed is the same as it would be if the bird were gliding the whole way round. There is no attempt to increase speed in order to make gain in height easier. In my notes I find the suggestion that perhaps the air has a structure, in virtue of which the soaring bird can only take energy from it at a particular speed, which speed may be different under different conditions. Evidence that I hope to bring forward in a later chapter will, I think, show that this suggestion only partially represents the actual facts of the case.

Apart from the gain in height, which does not necessarily occur in every circle, the circles described by soaring birds are practically always perfectly horizontal.

In a later chapter I hope to describe my observations on directive movements in gliding flight. It will then be possible to describe the movements of the circling bird in greater detail, but as will be seen, without in this way arriving at any solution of the mystery.

I have already stated that the tracks described by birds when circling are not circles. It is necessary to have records of the actual tracks made by soaring birds.

It occurred to me that if I watched the image of a circling bird in a looking-glass, with one eye closed, I could obtain a record of the track by following the

image of the bird with a pen. Obviously, too, more information would be obtained if, instead of making a continuous line, the pen was used to make dots at regular intervals of time. To obtain the intervals I used a metronome set to tick either at half-second or one second intervals. For the pen I used a stylograph containing copying ink suitably diluted. After the

record has been made a piece of paper is placed on the looking-glass and rubbed. Thereby a permanent copy of the record is obtained.

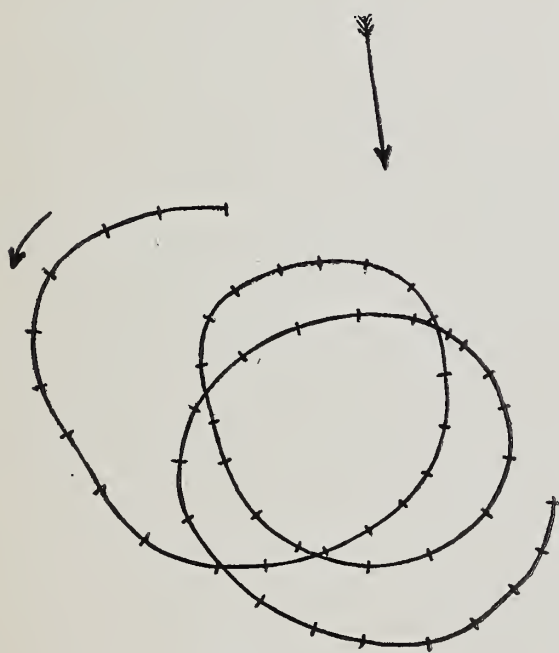


FIG. 1.

8th Jan., 1911, Jharna Nullah.—Track of cheel circling, marked at $\frac{1}{2}$ sec. intervals. Note lessened speed on windward side of track.

Fig. 1 is a looking-glass record of the track of a circling cheel marked at half-second intervals. At the time this record was made the wind was very light, scarcely enough to move leaves. Hence the bird shows but little leeward drift, and the successive circles overlap closely.

The time marks may be seen to be closer together on the windward side than they are on the leeward side of each circle. This means that the bird was travelling more slowly on the windward side of the track. There can be little doubt that this loss of speed is connected with gain of height, which, as already explained, usually occurs on the windward side of the circle. In this illustration, as in succeeding ones, the

large arrow indicates the direction of the wind. The small arrow shows the direction of flight of the bird.

More usually the circles overlap by a greater distance, as shown in fig. 2. In this case there is very little difference between the speeds shown on the leeward and windward sides of the circle. It is probable that it is a case of "ease-circling," that is to say, circling without attempt to gain height. The wind was very light, just enough to move leaves, when this record was taken.

In the presence of a slightly stronger wind the circles may overlap by a greater distance, as shown in fig. 3. In certain cases, especially in the presence of a strong wind, the intervals between the loops may be

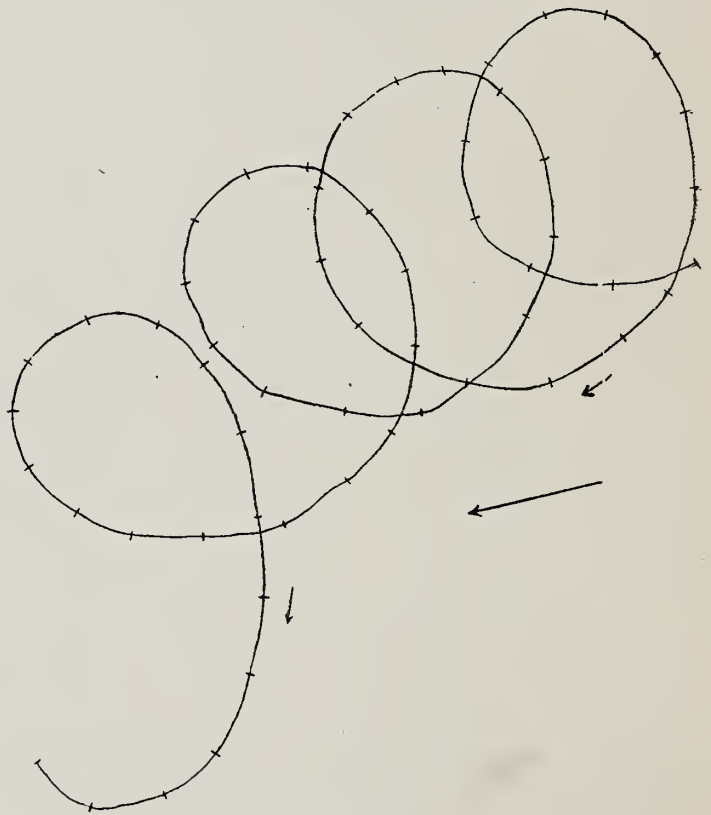


FIG. 2.

Track of cheel ease-circling in light wind. Time marks at 1 sec. intervals.

still greater. I propose the term "leeward looping" or "leelooping" to describe this latter form of flight. As shown in fig. 4, the diminution of speed indicating gain of height may occur chiefly at the point marked A, the point where the bird has turned round to face the wind. In some cases in leelooping, when observed at some distance from the side, there appears at this point to be a vertical gain of height of as much as 1 or 2

metres. In some cases in leelooping the bird appears to gain height during the whole of the loop. That is to say, it gains height not only while facing the wind, but also when going with the wind; in short, during

the whole time that it is on a curved course. Such a case is illustrated in fig. 5.

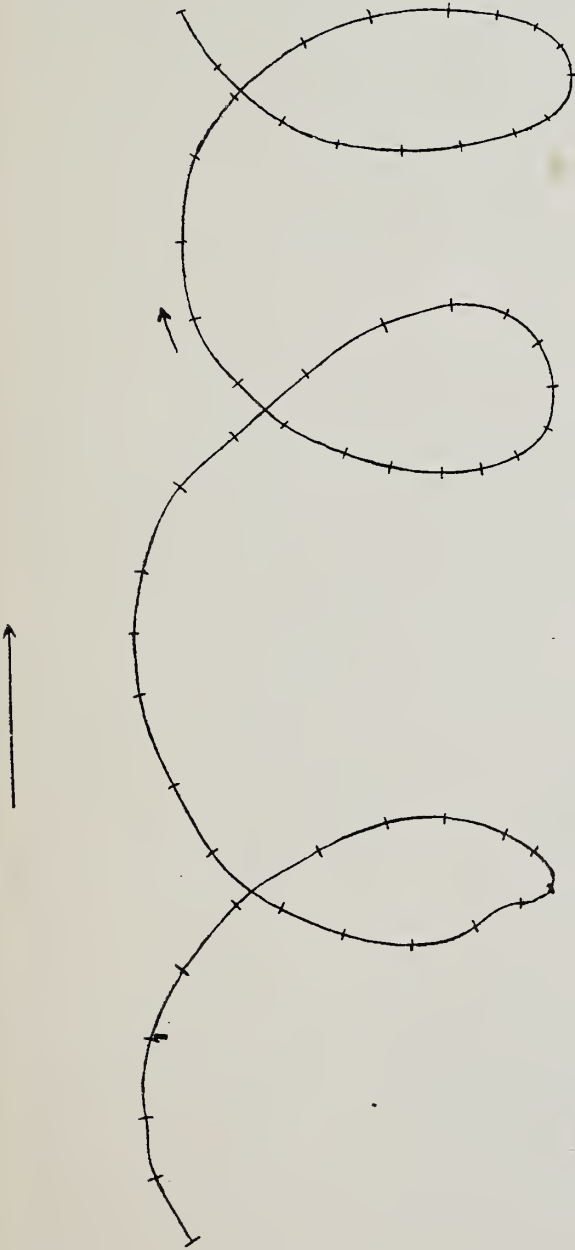
It might be thought that the difference between circling and leelooping depends merely on the presence or absence of wind. I doubt whether this is the case. For instance, the case of leelooping illustrated in fig. 5 was recorded in a light wind just strong enough to move leaves. I have on one occasion seen circling with scarcely perceptible drift to leeward in a strong, stormy wind.

FIG. 3.

8th Jan., 10.20, Jharna Nullah.—Thin cloud. Glare. Cheels had started at 9.31. No other species of birds up. Cheel circling marked at $\frac{1}{2}$ sec. intervals.

There can be no doubt that the amount of leeward drift in circling differs at different times, owing to factors not yet understood. I may quote the following diary extracts bearing on this matter:

July 14th, 1910. At 6.46.—Two cheels seen circling together. One changed its movement from circling to leelooping. Shortly afterwards



the other made a similar change. A minute later both birds glided down and settled. Widespread soaring began at 7.14.

September 29th, 1910. At 3.35.—An east wind, somewhat strong, moving branches. Sunshine. Isolated small cumulus clouds. Scanty clouds of higher layer. Four vultures seen circling in and out of the base of a small cumulus cloud at a height of 1,100 metres. Their leeward drift was not so much as that of the cloud. In a few minutes they were circling nearly overhead, and the cloud was far away to leeward. I made no record of the size of this cloud, but my recollection is that it was not larger in any dimension than eight or ten times the span of a vulture. Cheels and vultures were circling and flex-gliding to windward. They were leelooping when going to leeward.

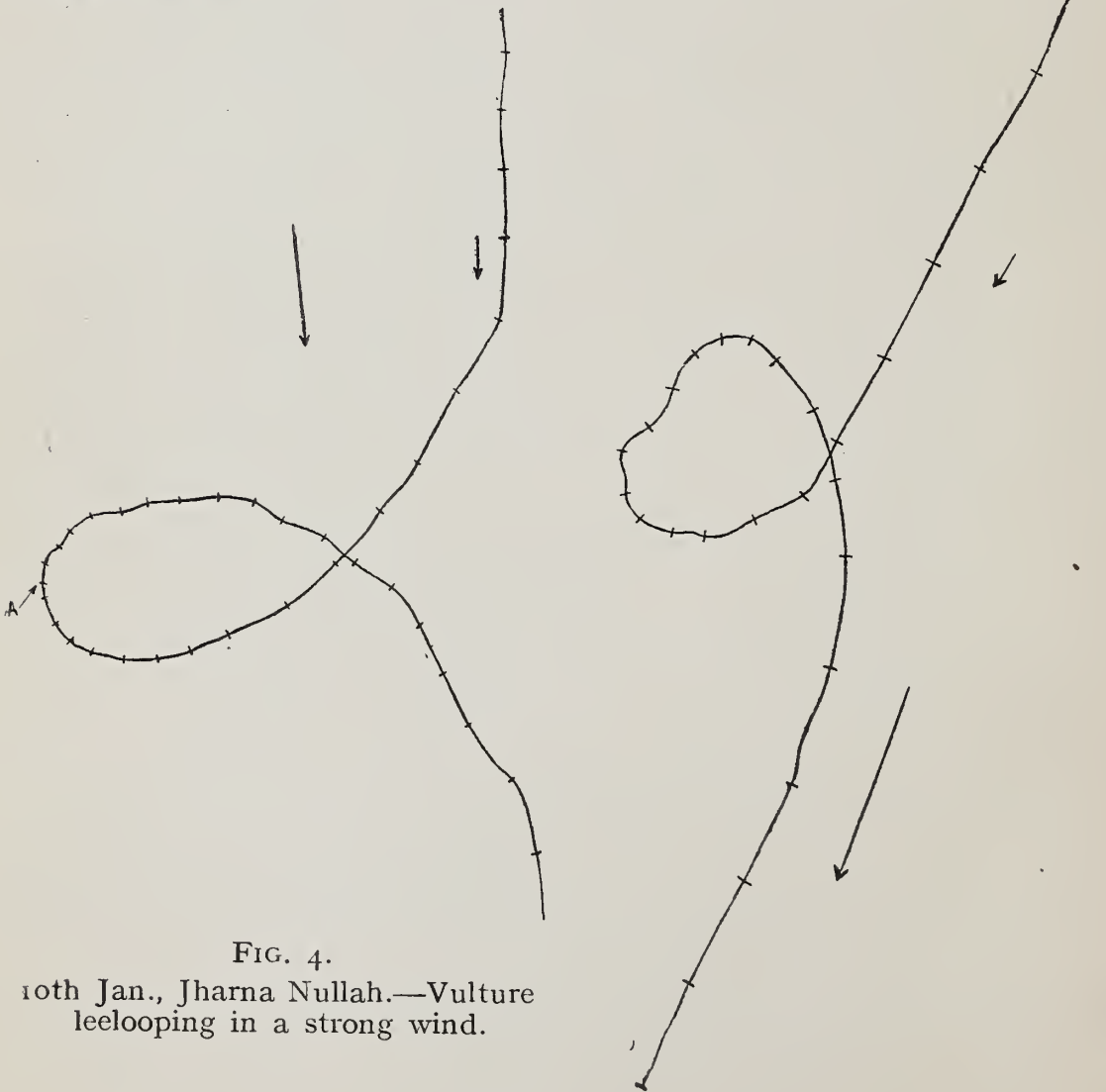


FIG. 4.

10th Jan., Jharna Nullah.—Vulture leelooping in a strong wind.

FIG. 5.

8th Jan., 1911, Jharna Nullah.—Scavenger leelooping. This was the first scavenger seen up. Cloud was getting thinner, and soarability was increasing. Previously cheels only had been circling. Note diminution of speed all round the loop. Track marked at $\frac{1}{2}$ sec. intervals.

Referring to fig. 5, it will be noticed that there is a somewhat sudden increase of speed immediately after the loop and at the commencement of the leeward glide. I have been able to observe the adjustment of the wings used to initiate this increase of speed, and shall describe it in a later chapter. The length of the leeward glide may, in some cases, amount to 100 metres or more.

We have now completed our preliminary description of circling. In this form of flight, as will be shown later, speed is relatively low, and, as has been stated, there is frequently a gain of height. We have now to make a preliminary description of another form of soaring flight, in which the bird travels horizontally, but at higher speed than is used in circling.

At first I was puzzled by the apparently large number of species of birds that were to be seen. In particular there was a large vulture, the underside of whose wings appeared yellow in front and black along the posterior margin. It carried its wings advanced so that the wing-tips were on a level with the beak. Another bird had the same colouring, but carried the anterior margin of its wings in a perfectly straight line with one another. Yet a third species was similar in colouring, but had the wings somewhat flexed, with the wing-tip feathers pointing outwards and backwards. It was only after some acquaintance with the subject that I discovered that these different birds were all of one species, namely, the common large vulture, but with their wings in different positions, according to the kind of flight in which they were indulging.

If a circling vulture is watched its wings will be seen to be in the dihedrally-up position. The amount of the

dihedral angle varies under different circumstances, as will be described in a later chapter. The wings are also fully extended, and if the air is highly soarable they are somewhat advanced, so that their tips lie on a level with the beak. Sooner or later a change in the mode of flight will be noticed. The bird is no longer canted over, as is usually the case in circling, but is seen to be gliding in a straight line and on a level keel. While

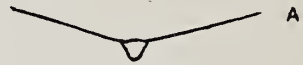
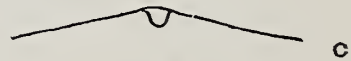
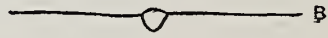


FIG. 6.

Diagrammatic end-on view of birds seen in end-on view with wings in different positions.

- A. Wings dihedrally up.
- B. Wings flat.
- C. Wings dihedrally down.
- D. Appearance presented by cheels when flex-gliding.
- E. Wings arched.



thus gliding the wings are no longer fully extended, but are more or less flexed. For this reason I propose the term "flex-gliding" for this form of flight. The speed can be seen to be greater than it is in circling, and the more the wing is flexed, that is to say, the more the span of the bird is diminished, the greater is the speed. In fig. 7 is shown the outline of a cheel when circling, but in this bird advancing of the wings under these circumstances is not well marked. In fig. 8 the cheel is

shown with wings slightly flexed, as seen in flex-gliding at low speed. In fig. 9 the outline is shown with wings strongly flexed, as occurs in fast flex-gliding. When seen



FIG. 7.

Outline of a cheel circling.

from behind and from a distance, the flex-gliding cheel has the appearance shown in fig. 6 (D).

That is to say, the inner portion of the wing appears to be curved upwards. For a long time the meaning of this appearance was unknown to me. In a later chapter I hope to describe the fortunate chance that led me to discover the meaning and nature of this adjustment.

In flex-gliding there is no dihedrally-up angle; the wings are perfectly flat, but as will be shown later, the centre of gravity is still at a lower level than the centre of lifting effort of the wings.



FIG. 8.

Outline of a cheel with wings slightly flexed, as seen in flex-gliding at low speed.



FIG. 9.

Outline of a cheel with wings strongly flexed, as occurs in fast flex-gliding.

Maxim gives this description of the flex-gliding of eagles:

"On one occasion a pair of eagles came into sight on one side of the plain, passed directly over our heads, and disappeared on the opposite side. They were apparently always at the same height from the earth, and in soaring completely across the plain they never once moved their wings. These phenomena, I think, can only be accounted for on the hypothesis that these birds were able to feel out with their wings an ascending column of air, that the centre of this column of air was approximately a straight line running completely across the plain, that they found upward movement more than sufficient to sustain their weight in the air, and that, whereas, as relates to the earth, they were not falling at all, they were in reality falling some four or five miles an hour in the air which supported them."¹

This description illustrates the excellent opportunities of observation that have fallen my way compared

¹ "Artificial and Natural Flight" (Whittaker and Co., 1909), page 19.

with the opportunities enjoyed by others. In the above-quoted case only two eagles were in sight. Therefore there was room to suppose that they were travelling along a ridge of ascending air. In Agra, at Jharna Nullah, on any fine calm day in the cold weather literally hundreds, if not thousands, of vultures may be seen flex-gliding in all directions and at all heights. That is to say, if, as Maxim supposes, this form of soaring flight is due to the birds being able to find ridges of ascending air, these ridges must, at Jharna Nullah, be uniformly distributed all over the sky as far as the eye can reach. Flex-gliding in all directions is most frequently seen on a calm day. In the presence of a strong wind, flex-gliding to leeward does not often occur. Most of the birds, wishing to keep within easy distance of the meat factory, circle or leeloop for going to leeward, and only use flex-gliding for travelling up-wind.

It is premature to speculate on the source of energy of flex-gliding. Speculation must be preceded by observation of the conditions under which this form of flight occurs and measurements of its speed.

I have made what I believe to be a new application of the telemeter, namely, in using it to measure the speed of gliding flight. I made white marks on a wall at intervals of 1 metre. I found that if I looked at these marks through the telemeter from a distance of 100 metres, the width of my field of view was 6 metres. At 200 metres distance the width of the field of view is 12 metres; at 300 metres distance it was found to be 18 metres, and so on. Consequently the speed of a bird, at a known distance, can be estimated by measur-

ing, with a stop-watch, the time of its passage across the field of view. For instance, suppose the distance of a flex-gliding vulture has been found to be 600 metres. Its time for crossing the field of view of the telemeter is found to be 2 seconds. The width of the field of view at 600 metres is known to be $6 \times 6 = 36$ metres. Therefore the bird travels 36 metres in 2 seconds. Therefore its speed is 18 metres per second.

This method, if rough, is at least simple and convenient. Obviously it only gives the speed over the earth, which in the presence of wind may be widely different from the speed through the air. Nevertheless it has been of use in enabling me to discover the different wing adjustments employed for different speeds, and also several unexpected facts relative to flex-gliding.

The following extracts from my diary illustrate the speed of circling :

21st January, 1910. At 3.45.—A vulture circling. On the up-wind side speed was 5 metres per second. On the down-wind side it was 9 metres per second.

24th January, 1910. At 10.45.—A vulture circling. On the up-wind side at 7 and $8\frac{1}{2}$ metres per second. On the down-wind side at 12 and 12 metres per second. Smoke ascending almost vertically.

19th February, 1910. At 9.46.—A vulture flap-gliding up-wind at 18 metres per second. 9.47.—This vulture was circling. Speed on up-wind side 7 metres, on down-wind side 12 metres. (At 9.11 wind noted to be west, and slightly moving leaves.)

20th February, 1910. At 10.7.—Four vultures seen circling at 400 metres height. 10.10.—They were found to be circling at 8 metres per second both on the up-wind and down-wind sides of the circle on the assumption that the wind was west. But smoke from the Cantonment Railway Station appeared to be rising vertically. Leaves were quite still. 10.21.—A vulture observed at 800 metres height. It was circling at 12 metres per second both on the up-wind and down-wind sides of track on the supposition that the wind was north or south. After two measurements had been made, it flex-glided to north at 16 metres per second. Shortly afterwards a light draught of air came from the east ; that is to say, the direction of wind was doubtful at the time of making the observation. Leaves were not stirring, and smoke was ascending vertically.

Measurements of the speed of flex-gliding have led to some interesting results.

In January, 1910, I found the following speeds of vultures in metres per second :

26, 25, 24, 21, 18, 16, 15, 10, 9, 9, 8, 6, 6, 6, 6.

In February, 1910, the following :

24, 21, 20, 20, 20, 20, 20, 19, 18, 18, 16, 15, 12, 12, 12, 10, 10, 10, 9.

In June, 1910, at Naini Tal, in the Himalaya Mountains, I measured speeds of :

24, 24, 24, 20, 18.

In July, 1910, I made a measurement of 20, and in August one of 22 metres per second in Agra. In January, 1911, I made a measurement of 18 metres per second.

In September, 1911, I recommenced these measurements. On certain theoretical grounds it appeared to me possible that flex-gliding could only occur between certain narrow limits of width of wing. The width of wing of the adjutant bird is about 16in. That of the vulture is 12in. I wished to see whether my impression was correct that adjutant birds flex-glided at lesser speeds than vultures. On measuring the flex-gliding speed of these birds I found very low figures. But I found the speeds of vultures were also low. The high speeds found in my earlier observations no longer occurred. From September to November, 1911, I made the following measurements :

Adjutants.—12, 12, 12, $8\frac{1}{2}$, 8, $7\frac{1}{2}$, 7, 6, 6, 6, 6, 6, 5.

Vultures.—16, 15, 14, 12, 12, $9\frac{1}{2}$, 9, 9, 8.

In December, 1911, January and February, 1912, I was away from India. But in March I recommenced my observations, and measured vultures flex-gliding at 16, 15, 14, 8, and 7 metres per second. But in April

high-speed flex-gliding suddenly recommenced. The following are extracts from my diary :

April 3rd, 1912. 12.45.—A large number of vultures seen flex-gliding near house at 600 to 700 metres up. They appeared to be moving more rapidly than usual. There was no circling. (This is a sign that the air had a high degree of soarability.) Speeds were measured of 18 and 22 metres per second. Another vulture, with wings in slow flex-gliding position, was travelling at 14 metres per second. Leaves still. Wind west, shown by smoke. Factory chimney smoke rising to about four times height of chimney.

12.50.—A vulture flex-gliding at 21 metres per second. Two other observations of same speeds. Cheels near showed no tail-jolting. The vultures were then flex-gliding away mostly up-wind.

1.2.—A vulture 500 metres up flex-gliding up-wind at 20 metres per second. Another at same height at 16 metres per second.

2.0.—A vulture at 100 metres height flex-gliding at 20 metres per second. Another travelling beam on to wind at 300 metres height at 20 metres. Cheels also were flex-gliding unusually fast.

Thin alto-cumulus cloud over sun, but sunshine.

3.29.—Vulture at 800 metres height going south at 20 metres per second. Leaves still. More cloud.

3.33.—No tail-jolting. No wind perceptible.

3.34.—A vulture flex-gliding up-wind at 12 metres per second at 600 metres height.

No wind perceptible.

3.36.—Calm. A cheel to windward seen to make ten tail-jolts in ten seconds. (This, as will be shown later, is a sign of transverse axis instability.)

3.37.—A puff of wind here moving small branches.

3.38.—A vulture 400 metres up flex-gliding to south at 24 metres per second. During the above observations, I noticed several times that swifts were using the dihedrally-up position of the wings with expanded tail for checking speed more often and to a greater degree than usual.

4.40.—Sky clouded. Glare. Wind moving small branches from north-west with puffs, and dusty. Soarability diminished. A vulture at 200 metres showed slight tail-jolting. Slow flex-gliding only seen for going up-wind. Swifts no longer using dihedrally-up position.

4.45.—The above vulture passed overhead at 10 metres height. Its wing-tips were only slightly rotated up. It was making very slight tail-jolts and changes in dihedral angle of its wings. It appeared to be descending to perch. Wind dropping.

6.30.—On Tundla Road. A prolonged grey dust-storm. Dust not thick. Vultures seen perched on a tree. No birds seen up. (A grey dust-storm is one that has come from a distance. If the storm originates near, the dust is seen rising in yellow masses.)

On four more occasions during April, 1912, I observed high-speed flex-gliding. On two of these

occasions I happened to record a thunderstorm that developed a few hours later. On thirteen other days during the same month, slow-speed flex-gliding only was observed.

Flex-gliding is the most important form of soaring flight. As will be shown later, it requires more energy than does circling. If it had been recognised before circling we should have heard less of the supposition that soaring flight is due to the bird being able to find ascending currents and to avoid descending currents. Flex-gliding birds often travel for miles in a straight line with no discoverable movements of the wings or deflections from their course. If the air energy available is not sufficient for flex-gliding, and the bird has to glide with loss of height, this loss of height can be easily recognised. That is to say, it is highly improbable that in flex-gliding there is any loss of height that could at the same time be overlooked and also be sufficient to produce a speed ahead of 24 metres per second.

If flex-gliding is due to the bird taking advantage of ascending currents, then these currents must be relatively strong on days when fast flex-gliding occurs, and relatively weak on days when slow flex-gliding occurs. Strong and weak ascending currents cannot occur on the same day mixed together, as if this were the case, as will be proved later, instability of a particular kind would be produced. This instability would cause to and fro movements round either the longitudinal or the dorso-ventral axes.¹ These kinds of insta-

¹ A bird when gliding may be considered as having three axes that cross each other at right angles. The "longitudinal axis" extends from the beak to the tip of the tail; the "transverse axis" from wing tip to wing tip; the "dorso-ventral axis" is the axis which is vertical when the bird is gliding horizontally.

bility are never observed in air capable of yielding sufficient energy for fast flex-gliding, as will be shown in greater detail on a later occasion.

I mention these facts out of their proper order merely to warn the reader that speculations about ascending currents do not appear likely to lead to an explanation. What is wanted is more observation and more measurement. With flex-gliding, as with other phenomena of soaring flight, it is only the first observations that suggest an easy explanation. Further observations reveal facts impossible to explain with the help of recognised theories.

FIG. 10.
End-on view of a vulture flex-gliding in a straight line, but in a canted position, and travelling in a direction at right angles to the direction of the wind.



I have now to describe a very remarkable phenomenon which clearly shows that the problem of the nature of soarability must be solved by serious research and not by idle theorising.

As a rule a bird when flex-gliding travels on a level keel. But during the cold weather of 1909-1910 I noticed that the heavier birds, when flex-gliding in a direction at right angles to the wind, appeared to be canted over away from the wind, as shown in fig. 10, although their course appeared to be a perfectly straight line. At first I thought that the appearance was illusory. It was conceivable that in order to allow for drift the bird might not head in the direction towards which it wanted to go, but towards some point to windward of this direction. But at last I noticed that

such "heading" only occurs when the wind was strong, whereas canted flex-gliding was, as a rule, only observed when the wind was light. During January, 1910, it often happened that two or three vultures at a time could be observed flex-gliding beam on to the wind in a canted position. The following extracts from my diary illustrate my observations on canted flex-gliding :

March 4th, 1910. At 1.30.—A large group of vultures came towards me flex-gliding up-wind. The wind was west and very light, slightly moving leaves. When near me the vultures turned to the north. In doing so they became canted over away from the wind, and remained thus canted over while gliding away in a straight line till out of sight. They were at different heights. One or two were quite low down, perhaps from 100 to 150 metres up.

March 16th, 1910. At 4.16.—Some thin cloud but no cloud shadows. Blue sky overhead. Wind light, and moving leaves. Several vultures showed canting.

March 27th, 1910. At 5.20.—A vulture seen to the north, probably about a mile distant, and 500 metres up. It was flex-gliding, beam on to the wind, which was west. It was canted. It passed overhead showing absence of heading. When it had passed over me towards the south, it was still seen to be canted. After proceeding south for about a mile and a half, it got on to an even keel for a few seconds, then turned to the east, and began circling. The wind was light, only slightly moving leaves. Factory chimney smoke was rising high.

The first entry in my diary relating to canted flex-gliding is dated November 9th, 1909. It was only in March, 1910, that I convinced myself of the reality of the appearance. The extraordinary part of the matter is that whereas during the cold weather of 1909-1910 canted flex-gliding must have been of common occurrence, from March, 1910, it only occurred on very rare occasions. After March 27th I did not see canted flex-gliding again for four months. The observations were as follows :

July 28th, 1910. At 4.0.—Clouded over. Wind north, puffy, and moving branches. Circling vultures showed rapid drift to leeward. A group of five was noticed, after circling, to flex-glide off with the wind on their beam. All showed canting. A few minutes later two other vultures were seen flex-gliding in a canted position.

August 2nd, 1910. At 4.20 to 4.30.—Two vultures seen flex-gliding to leeward, and eight vultures canted flex-gliding beam on to wind. The wind was then puffy, moving smaller branches during puffs.

August 14th, 1910, at Futteypur-Sikri. 4.1.—Lull in wind. Previously it had been moving branches, and now only leaves. Low level flapping noticed (a sign of afternoon decrease of soarability near the earth). Strong sunshine. 4.10.—Four vultures seen canted flex-gliding to north-west. They were at about 800 metres height. Wind south-west and puffy.

August 20th, 1910. At 5.0.—Three vultures seen canted beam on flex-gliding. After about 45 seconds they got level and turned gliding to north.

The above observations in July and August had been made during the monsoon season. Canted flex-gliding was not again observed till cold weather conditions had been established. These observations were as follows:

October 18th, 1910. At 4.30.—A large number of vultures and one adjutant circling. Much canted flex-gliding was seen. At one moment I counted forty-one vultures in canted flex-gliding. They were all canted over to the same amount. One that was fast flex-gliding was canted to the same degree as the others. The wind was west and very light, leaves being generally still.

October 21st, 1910. At 5.0.—Group of cranes seen at about 300 metres height canted flex-gliding with occasional flapping.

January 16th, 1911. At 3.15.—A vulture seen canted flex-gliding to north. (The wind was west.)

3.17.—A vulture coming up towards me beam on to the wind was canted. It was 400 metres up and travelling at 18 metres per second. When overhead it was seen to be going straight—that is to say, absence of "heading." When it had passed over it was again seen to be canted. Near it was a scavenger vulture also canted.

3.25.—A vulture canted flex-gliding for a short distance.

3.33.—A vulture and a brown vulture going to the north canted.

3.34.—A scavenger seen fast canted flex-gliding to north.

3.36.—A vulture at 300 metres height canted flex-gliding. Vultures circling at the time had wings only very slightly advanced. (Observations began at 3.15, and now discontinued.)

Canted flex-gliding was also observed on the 21st February, the 20th March, the 30th March of 1911, and the 20th May, 1912. Since this last date up to the time of writing the phenomenon has not been again observed.

Cheels when flex-gliding in an ascending current of air over the battlements of the Agra Fort keep on a level keel so long as they travel in a straight line. Hence it is difficult to see how speculations about ascending currents can help us to understand the nature of canted flex-gliding.

I am acquainted with various dispositions of wings and modes of flight that occur at one time of the day and not at another, or at one season of the year and not at others. With our present knowledge it is not impossible to suggest explanations of such changes. But a mode of flight that occurs commonly in one year and rarely in another indicates the concurrence of meteorological factors whose nature is at present completely unknown.

Two other forms of soaring flight remain to be mentioned, namely, ease-gliding and lift-gliding.

On any fine day after soarability has been established, a large number of birds of different species may be seen circling and gliding over the Jharna Nullah Factory. At intervals a cluster of birds will become separate from the rest and commence to drift, circling more or less directly to leeward. Sometimes as many as half a dozen clusters, each containing one or two hundred birds, may be seen at one time. Sometimes I have noticed that the starting of a cluster of birds to leeward was coincident with the coming of a puff of wind. After the cluster has drifted one to three miles to leeward it breaks up, and the birds that had formed it may be seen flex-gliding either directly up-wind to join the original group of birds over the slaughter house, or else they flex-glide in different directions to join other

groups of circling birds. A bird leaving the top of a cluster of birds three miles to leeward, after flex-gliding

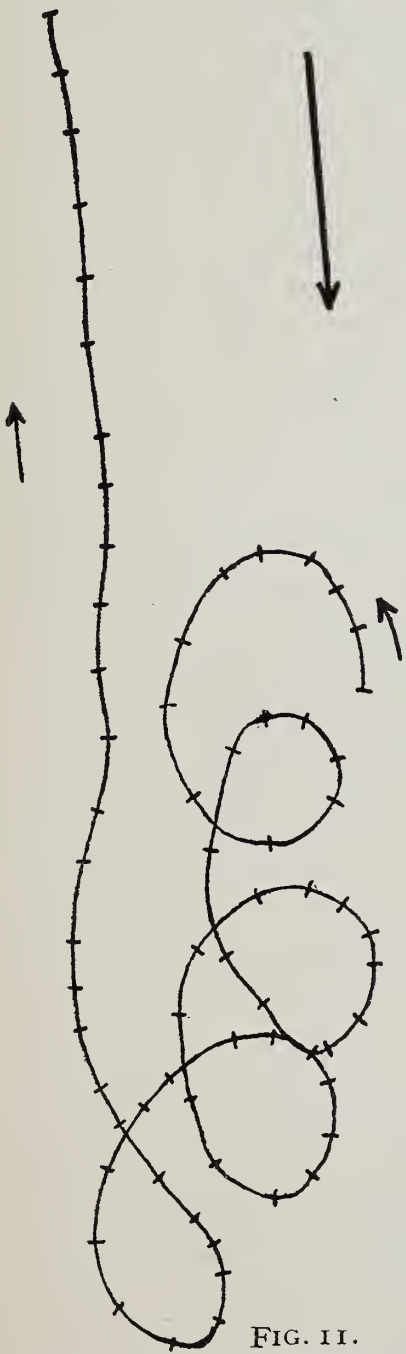


FIG. II.

that distance up-wind joins another cluster at the top, not at the bottom. That is to say, in flex-gliding this distance there is no evidence of loss of height. In a light wind the birds may be seen to be flex-gliding at low speed with wings only slightly flexed. If the wind freshens, all the birds in sight may be seen suddenly to increase the flexing of the wings which, as will be explained later, is part of the adjustment necessary for flex-gliding at higher speed. Fig. II is a looking-glass record of the track of a cheel first circling and drifting with the wind and then flex-gliding up-wind at low speed.

Some time after morning soarability for cheels has been established, these birds may be

8th Jan., 1911, Jharna Nullah.—Cheel circling and then flex-gliding up-wind at slow rate. At the time there was thin cloud, and no fast flex-gliding had occurred. A few minutes later, as cloud got thinner, fast flex-gliding of cheels began. Track marked at 1 sec. intervals. Wind at the time not strong enough to move leaves.

seen gliding in irregular curves, without gain or loss of height, and at moderate speed. I propose the term "ease-gliding" for this form of flight. Scavengers also

indulge frequently in ease-gliding. But the heavier vultures less often use this form of flight. Fig. 12 shows the track of a cheel while ease-gliding. Ease-gliding of a vulture is shown in fig. 13.

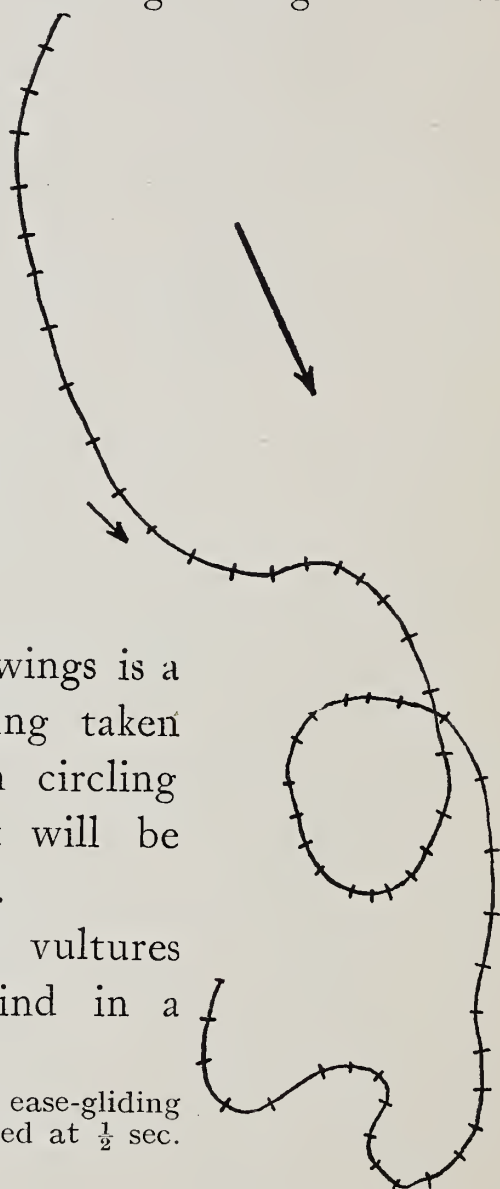
In the case of vultures when ease-gliding, the wings are held flat and the front margins of the two wings are in one straight line, that is to say, there is no dihedrally-up angle and the wings are not advanced.

That this disposition of the wings is a sign that less energy is being taken from the air than occurs in circling with effort to gain height will be explained in a later chapter.

In rare cases cheels and vultures may be seen gliding up-wind in a

FIG. 12.

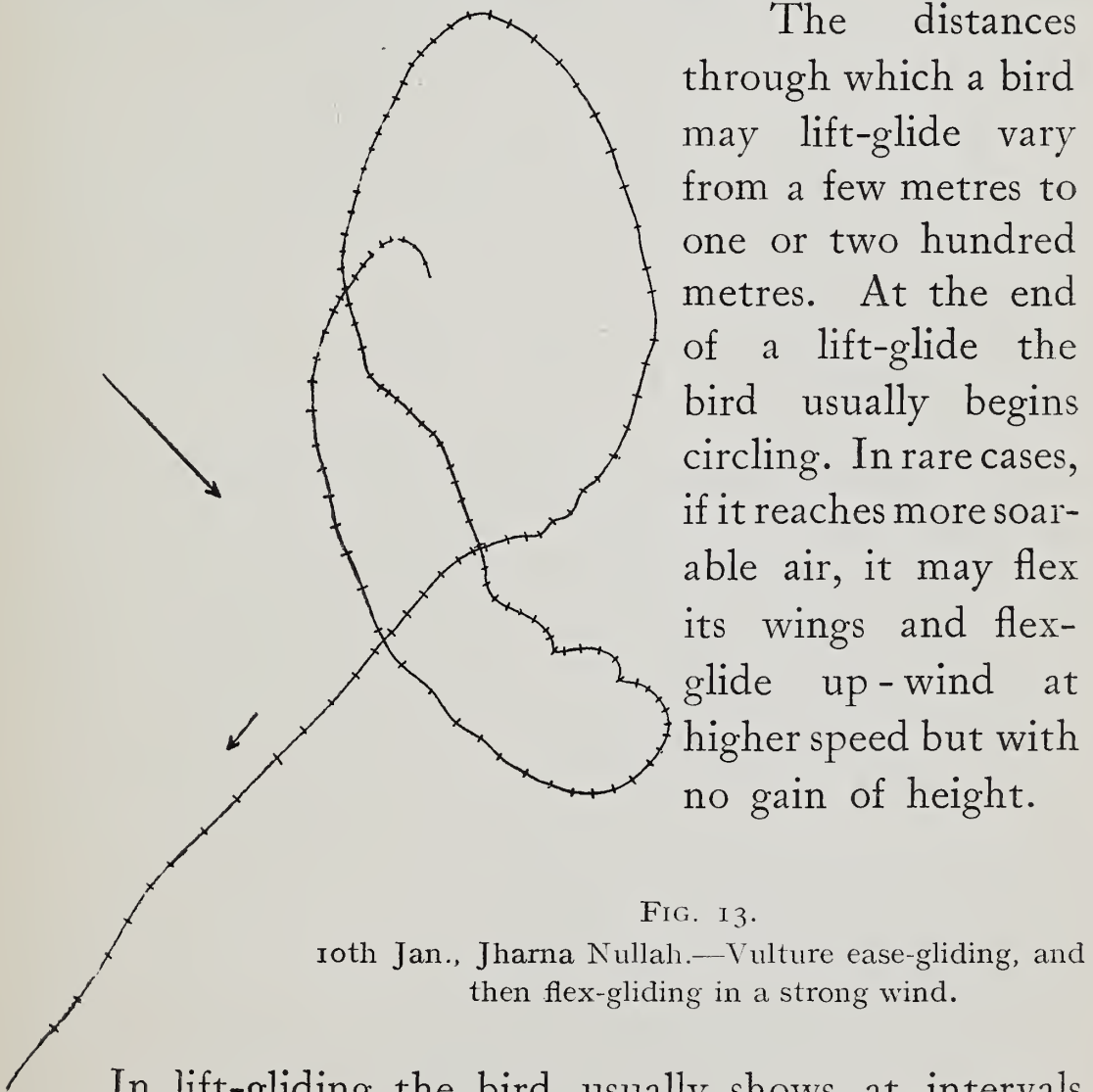
8th Jan., 1911, Jharna Nullah.—Cheel ease-gliding and making one circle. Track marked at $\frac{1}{2}$ sec. intervals.



more or less straight line with gain of height. This form of flight occurs in cases in which there is sufficient air energy for circling, but not enough for flex-gliding. If still less energy is available, birds glide up-wind with loss of height. In either of these cases the wings are kept fully extended, and, as will be shown later, the wings are at a maximum camber.¹ In flex-gliding on the other hand the camber is decreased

¹ "Camber" is concavity of the underside of the wing in a fore and aft direction. The mechanism for changing camber is described in Chapter VII.

or abolished, and the speed ahead is greater. I propose the term "lift-gliding" for gliding in this way, *i.e.*, in a more or less straight line, with the wings at maximum camber, with or without gain of height.



The distances through which a bird may lift-glide vary from a few metres to one or two hundred metres. At the end of a lift-glide the bird usually begins circling. In rare cases, if it reaches more soarable air, it may flex its wings and flex-glide up-wind at higher speed but with no gain of height.

FIG. 13.

10th Jan., Jharna Nullah.—Vulture ease-gliding, and then flex-gliding in a strong wind.

In lift-gliding the bird usually shows at intervals small rotations to and fro round the dorso-ventral axis. Either this phenomenon is due to this form of flight being, for some unknown reason, necessarily unstable, or on the other hand the instability is due to some defect in the air in which the bird finds it necessary to lift-glide. Observation of cases of stable lift-gliding appear to point to the second alternative as being more probable, as will be described in a later chapter.

CHAPTER III.

PRELIMINARY ACCOUNT OF THE CONDITIONS NECESSARY FOR SOARING FLIGHT.

One of two conditions is necessary for soaring flight to take place in Agra: Either there must be sunshine or there must be wind. If there is no sunshine, or at least no strong glare of light, and no wind, then soaring ceases and all soaring birds return to earth.

In the presence of sunshine during the day the air is always soarable. Proofs that the rays of the sun are the source of the energy involved will be given in later paragraphs. In the presence of wind two kinds of soarability are met with. The first may be called "false soarability." In this the birds demonstrably take advantage of ascending currents reflected upwards from trees or buildings. In false soarability the birds only rise to moderate heights, and the heights attained are proportional to the strength of the wind. Only the birds of lighter loading, namely cheels and scavengers, as a rule take advantage of ascending currents in this way. In the second kind, or true "wind soarability," birds usually take care to avoid ascending currents reflected upwards from buildings, reach much greater heights, and cover greater distances than they do in the case of false soarability. The heights attained are very frequently not proportional to the strength of the wind. All species of soaring birds take advantage of this true wind soarability. Other differences between

true wind soarability and false soarability will be apparent when we come to describe the phenomena of instability.

It is necessary to give a proof that in sun soarability the sunshine is the source of the energy involved. It is also necessary to prove that the sun energy is available for soaring flight, apart from the presence of wind. The fact that soaring flight commences at a definite time of the day, earlier in summer and later in winter, is a proof that sun energy is involved. Further proofs will be found in the chapter dealing with the complicated relation of cloud shadow to soarability, and especially in the description of soaring flight in Naini Tal. The proof that wind is not the source of energy in sun soarability is chiefly indirect. The facts to be described in this and other chapters will be found to prove that the energy available for soaring flight in sun soarability is proportional to sunshine, and that it is not proportional to wind.¹

The species of crow found in Naini Tal, as already stated, only soars when the air is perfectly calm. I have observed crows circling in calm air in Naini Tal both at my level, above me, and below my post of observation. It is impossible to prove that movement was absent from the air during these observations. But observations of pieces of cloud material resting on the hills near showed conclusively that that kind of movement of the air properly described as wind was absent.

I have already stated, and will prove later, that more air energy is required for flex-gliding than for circling. On rare occasions all vultures in sight over

¹ For further proofs that wind is not necessary for sun soarability, see entry "Soaring Flight" in index.

Agra may be seen to be flex-gliding. No circling is taking place. This is perhaps evidence that the air has a higher degree of soarability than normal. More often, and as a rule, both circling and flex-gliding occur together. In other cases in which soarability is diminished owing to the presence of thin cloud, circling may occur, but no flex-gliding. So far as my experience goes, cases of an exceptionally high degree of soarability usually only occur when the air appears to be calm or nearly so. By "calm," I mean that available evidence shows that wind is absent. That movements of parts of the air exist in the apparent calm I shall show later, and I shall bring forward evidence as to whether or not these known movements are the cause of soarability. Apart from these movements, it might be suggested that in spite of the apparent calm perhaps the air as a whole is in movement, that is to say, it is possible that there is actually a small amount of wind too small to detect. If this is admitted we have not arrived at a proof that wind is necessary for soaring flight in the presence of sunshine. On the contrary, the fact that less wind is observed to be accompanied by more soarability is a proof that one phenomenon is not the cause of the other.

If a column of birds is drifting to leeward from the Jharna Nullah Factory, it is a general rule that the upper part of the column is further to leeward than the lower part. No doubt this exemplifies the known rule that wind is greater at a height than nearer the earth.

Whether or not there is an appreciable amount of wind at a height may be learnt by observing the move-

ments of birds. In the absence of wind at a height, circling birds show no drift to leeward. In the presence of wind the circling birds may be seen to be slowly or rapidly drifting to leeward. A difference is also observed in the case of flex-gliding. In the absence of wind, flex-gliding birds travel in the direction in which they are pointing. In the presence of a strong wind the flex-gliding bird does not necessarily travel in the direction in which it is pointing. If it wishes to travel in a direction abeam to the wind, it points in a direction intermediate between the place to which it wishes to go and the direction from which the wind is coming. This mode of flight may be described as "heading." Heading is always a sign of the presence of wind at a height. Cheels, especially when at low levels, in a strong wind, may show a form of flight that I propose to term "wind-facing." In this form of flight they so adapt their speed to the strength of the wind that they remain nearly in one position over the earth. They occasionally glide for a short direction up-wind, but more usually are heading first in one direction and then in another. By "poised-gliding," I mean that a bird in a wind glides with its speed checked when necessary, and remains as if fixed in the air in one position, without flapping. Cheels never behave in this way. The term "poising" or "poised-flapping" may be ascribed to that form of flight in which the bird remains fixed in one position in the air with the help of rapid flapping, as shown in India by the Pied Kingfisher, and in England by the Kestrel Hawk.

Whirlwinds or "dust devils" frequently occur in Agra on warm days when the air is nearly calm. A dust devil

consists of a column of air in rapid rotation in which dust, pieces of paper, and leaves, are lifted. It may be three or four metres in diameter, and may reach a height of several hundred metres. At its upper extremity the column of dust expands forming a light yellowish cloud which persists for some time after the column of dust from which it arose has vanished. The air in the immediate neighbourhood of a dust devil appears to be rising, for I have seen a piece of paper carried up in a slanting direction to a great height, possibly 800 metres, before it went out of sight when followed with a binocular.

Soaring birds in Agra appear to take no notice of these dust devils. In Rajputana, on the other hand, dust devils are far more common, and cheels frequently amuse themselves by gliding in and out of them. Mr. V. Bayley, P.W.D., to whom I am indebted for this information, tells me that sometimes half a dozen dust devils are visible at once looking like a row of factory chimneys. As in Agra, they only occur in hot weather and when the air is nearly calm. Sometimes a dust devil of a few inches in diameter becomes visible at ground level and grows to one of several yards across within a few seconds. Mr. Bayley supposes that this is due to a dust devil that has formed at a height descending to the earth. Occasionally he has been able to detect a dust devil at a height in the air partly by movements of cheels and partly by movements of the suspended dust. In hot weather much dust may be present in the air at a height even when the air is very nearly calm.

On several occasions during October, November, and December of 1909 (but not during the same months of 1910) I saw pieces of jawar leaf or pieces of grass

floating in the air. There can be no doubt that they had been carried up by "dust devils," and that when I saw them they were falling. In all cases their horizontal movement was very slow, indicating that at the height at which they were observed the wind was as light, or nearly as light, as it was near the earth. Knowing the probable sizes of these pieces of leaf it was possible to make a rough estimate of their height which on some occasions may have been as much as 200 metres above ground level.

On the 8th February, 1910, I saw a boy's kite floating free in the air at a height far above that at which it is likely to have been flown. As these native kites are nearly always of the same size I was able to make an estimate of its distance. It was at about 1,000 metres distance. It was probably 500 metres above the earth. It was only visible to the naked eye when the sunlight fell on its white surface. The wind was so light that its direction of fall made an angle of 10° to 20° with the vertical. It was watched till it went out of sight behind some trees. Several birds were circling and flex-gliding near. It may be explained that these native kites are so light that they can be flown by a skilled operator in a wind that is scarcely perceptible.

I have nearly a dozen entries in my diary of pieces of paper or feathers being seen floating in the air. On one occasion a feather was seen in the midst of a cluster of circling cheels, and its motion was noted as being imperceptible. Once a feather was seen to drop off a cheel, and showed by its almost complete lack of motion the small amount of movement in the air. During October and November, at Jharna Nullah, when one or

two thousand birds may be circling and gliding together, it is rarely necessary to wait for more than a few minutes to see one or more feathers floating in the air to leeward of the clusters of birds.

In the calm weather that often occurs in October and November after the close of the monsoon season, smoke from factory chimneys can be seen rising vertically to an immense height. I have seen this smoke reach a height that I estimated as being nine times the height of the chimney. The chimney is 135ft. high; hence its smoke must have reached a height of 430 metres. Vultures in the neighbourhood were circling at lower levels.

On a calm morning during the cold weather a light mist composed I believe of smoke and dust commonly lies over the city and country. It is not very thick. Usually a factory chimney three miles away is visible through it. The smoke from this chimney can be seen dimly rising through the mist and spreading out in all directions horizontally forming a layer like a thin cloud. As the sun gathers power the smoke may be seen piercing this layer and rising vertically. To all appearances the air is completely calm. It is very striking to see the cheels rise circling in and through this mist. Their time of starting is not in the least delayed by the complete absence of wind.

The appearance of rest in the air is, however, illusory. Rising currents of air formed under the influence of the sun's rays are already beginning. These "heat eddies," as I propose to call them, can best be seen through a binocular held firmly in a clamp. As the heat eddies develop the edges of the flat roofs of

buildings may be seen to acquire an appearance of shimmering and quaking. The heat eddies though far more mobile and active resemble the waves of an angry sea. The slightest wind causes them to appear to run along the lines of the buildings. Observation of these eddies can be used as a test to see whether or not wind exists. It is a test far more delicate than the sense of touch, and even perhaps than observing the movement of smoke. On two occasions during the cold weather of 1910-1911 I have seen complete absence of wind as tested by heat eddies, and on each occasion the circling of wheels began at its normal time.

In view of the above facts, there can be no doubt that it is inaccurate to describe the soaring bird as getting its energy from the wind. In other words, in attempting to discover the source of the energy of soaring, the movement of tangible masses of air that we know as wind must be left out of account.

On a fine day at Jharna Nullah, when the wind is just perceptible, it is easy to follow a feather floating in the air a few metres above the earth travelling horizontally for some such distance as 50 or 100 metres. Although the air is full of heat eddies the feather shows no appreciable deviation from its course or appreciable change in velocity. It has been suggested that there may be circular eddies in the air, that a feather might be depressed by the descending part of the eddy, while a bird was being lifted by the ascending part. I have no wish to deny the possibility of this happening, but I venture to point out that under the conditions described no evidence exists that a floating feather can be either raised or depressed to a visible

extent by air eddies known to exist.¹ I have, however, on one occasion noted that a piece of leaf falling through the air appeared to fall at a greater speed when it passed out of sunshine into the shadow of a building. In spite of the obvious probability that this appearance was an optical illusion, it would be of interest to investigate whether feathers floating in soarable air without appreciable loss of height would float similarly in unsoarable air.

A remarkable and important characteristic of circling flight, namely its regularity, can only be seen and appreciated with difficulty in the case of vultures, but can be readily observed in the case of cranes. I was once watching between 50 and 100 cranes starting from the river bed beyond the Taj. They were flap-gliding in large circles until they reached a height between 100 and 200 metres. They then circled without flapping. Their leeward drift indicated that the wind was north-west. As I had been under the impression that the wind was west (it was very light at the time) I at once sent a boy to fly a kite, and found thereby that the wind was north-west as has been indicated by the drift of the circling cranes.

In the case of vultures, the point round which they circle is situated somewhere near the centre of the cluster of birds. In the case of cranes, this central

¹ Mr. E. F. Andrews, in the *Aero* for July, 1912, page 205, describes the following observations on soaring flight made at Daytona Beach, Florida. He says: "The turkey buzzard, who will, before one's very eyes, calmly glide upwards on motionless wings, as if such a thing as gravity never existed, has to me been a source of perpetual wonderment. Many times, after watching him wheel in ever highering circles only a few feet above my head, have I tried every means at my disposal to detect the rising current that supported him. I have liberated thistle-down and the lightest feathers with the bird soaring twenty-five feet overhead, and to my surprise these indicators always fell to the ground. Not satisfied with this, I flew up a kite with a bag of feathers attached in such a way that a jerk on the string would liberate a cloud of them. Sometimes one of these would be caught in a rising wave of air, which would elevate it several feet; but after travelling a short distance it would encounter a downward wave that would lower it again, and in time they seemed always to come to earth. These experiments, of course, do not prove that rising air currents do not exist. They do prove, however, that soaring flight can be accomplished when no rising air currents exist of sufficient velocity to support a feather."

point is not inside the cluster but outside it at a distance of perhaps 200 metres or more from the group of birds.

The birds form a compact group as they glide round this central point. The remarkable feature of their flight is the regularity and exactness with which they keep their distance from one another. If anyone was shown such a group of cranes through a binocular without being told what he was looking at, he might easily believe that he was looking at a number of dead birds pinned on to a wall, all pinned on with their wings in exactly the same position. While the cranes were on the up-wind side of their track they looked black in colour against the background of pale blue sky. As they neared the windward side and gradually turned, they appeared to diminish in size till suddenly they were visible in end-on view, each bird then looking like a black inclined line with a central dot representing the body. The change from the side view to the end-on view appeared to take place within one or two seconds for the whole group. As the birds turned from the windward side to the down-wind side of their track, the change was equally sudden. Within one or two seconds, as it seemed to me, every bird had changed its appearance, and now showed the upper surfaces of its wings, which appeared nearly white in colour from the reflected sunlight. Towards the end of the down-wind glide perhaps one or two birds showed occasionally some slight deflection (not beating) of their wings. Then came the sudden change to end-on view which the birds presented along the leeward side of their track. While thus circling the cranes were rapidly gaining height and

in a quarter of an hour reached a height of about 1,200 metres. They then reversed the direction of their circling once or twice, still keeping in a compact group. They then flex-glided away in a northerly direction, and in so doing arranged themselves side by side in a long line dented in the middle, like a letter V, but with an obtuse angle, and with its apex forward. The birds were at regular intervals, and kept their distances with almost the same marvellous regularity as they did when circling. Their flex-gliding was canted. Every bird was canted to the same degree, and remained so till out of sight. (Date of observation, 28th March, 1910, at 4.15.)

This regularity of the gliding flight of cranes when circling or flex-gliding has a certain theoretical interest.

It has already been shown that the soaring bird does not get its energy from the wind. Therefore it must get its energy from the air. Unless the bird actually changes the air by its passage it is impossible for it to get energy from the air if the latter is homogeneous. Therefore on the latter view soarable air must be heterogeneous. Because cranes when soaring do so with regularity, therefore they must get their energy from the air at a constant rate. Therefore the heterogeneity of the air must be fine grained. This conclusion may be expressed more clearly in another way. My friend Dr. Morris Travers of the Indian Institute of Research, suggested to me that possibly soaring birds might get energy by meeting eddies and extinguishing their motion. The suggestion appears to me of interest as the first formal theory of the nature of soarability that I have heard of that has due regard to the facts of the case.

Supposing it is true, then since the bird gets energy by meeting eddies at a regular rate, such eddies must be in small comparison with the size of the bird, and must be uniformly distributed.

This regularity in the flight of circling cranes is a phenomenon of importance. It is a fact that directly contradicts the idea that soaring flight is due to the bird being able to find ascending currents and avoid descending currents. It is a phenomenon that can be observed by anyone without any special training. The fact that it is easy to see does not detract from its importance in estimating possibilities as to the nature of soaring flight.

In view of the results already described it is certain that soaring flight cannot be due to the bird taking advantage of chance currents of wind. Something of a more uniform and regular character must be looked for in soarable air. Whatever the cause is it must be widely and regularly distributed as will be proved also by other facts to be described in later chapters. In the above-described case the cranes, after circling, flex-glided away out of sight. There is every reason for believing that had they flex-glided away in any other direction than they did, they would still have found sufficient air energy to propel them horizontally at a uniform speed of perhaps 30 miles an hour.

So far as the present evidence goes, it is logical to investigate any movements of the nature of eddies in soarable air, even if they are of microscopic or ultra-microscopic size.

I may mention here some atmospheric changes that commonly accompany the morning development of

soarability in fine weather. Smoke from factory chimneys in the unsoarable air of the early morning shows no tendency to rise to a height. As soarability develops it usually rises to varying heights above the top of the chimney. For instance :

15th May, 1912. 6.5.—Wind S.S.W., occasionally moving small branches.

6.20.—Smoke in masses not rising above level of chimney tops.

7.5.—During the period of observation the wind has been nearly steady, and slightly moving small branches.

7.10.—Smoke at chimney top level.

7.11.—Smoke slightly above chimney top level.

7.23.—Smoke one chimney length (155ft.) above chimney tops.

7.26.—Cheel circling high near the house.

7.27.—Puff of wind here raising dust. Above cheel gliding up-wind, showing signs of transverse axis instability.

7.30.—No cheels up in city.

7.32.—Eight cheels circling in city and three near.

7.42.—Four cheels near gliding up-wind. Secondaries not relaxed. They travelled for the most part horizontally, but with occasional loss of height. They showed slight single wing depressions (lift-gliding, a proof that air energy was not sufficient for flex-gliding).

7.44.—Smoke two chimney lengths up.

Besides showing a tendency to rise in soarable air, smoke from factory chimneys often shows change in behaviour as soarability develops. In the unsoarable air of the early morning smoke drifts to leeward if there is a light wind, forming a long horizontal band. This smoke layer may extend along a third of the horizon, or even more. Its upper and lower margins are indistinct. Near the chimney it may show the irregular outline characteristic of smoke masses during the day. But from a little distance from the chimney these irregularities vanish and the smoke extends in level layers with diffuse outline. At about the time that soarability develops smoke shows a change in behaviour. Besides showing a tendency to rise, it

keeps the form of irregular masses until it dissolves. For instance :

14th May, 1912. 5.0.—Twilight. Smoke in layers. Wind east, occasionally moving leaves.

6.52.—Smoke in layers.

7.12.—Smoke higher. Less in layers.

7.22.—Cheel near circling.

7.25.—No cheels up in city.

7.29.—Smoke in irregular masses.

7.30.—Four cheels circling in city.

7.35.—Nine cheels up in city.

But this appearance of diffuseness of smoke has no constant relation to soarability. On the 13th April, 1912, for instance, I noted that smoke was in masses before soarability developed and diffuse shortly after it had developed. I have also seen diffused smoke in the nearly calm unsoarable air succeeding a storm (27th March, 1912). On the contrary I have seen in rainy weather in the monsoon season smoke rising to a great height in masses in an unsoarable wind.¹

A more important atmospheric change that accompanies the development of sun soarability, namely the development of "heat eddies," will be described in a later chapter.

¹ Wegener has observed smoke in diffuse layers in the early morning in Germany. He states that this appearance is due to the absence of turbulent movements in the air. He also suggests that the presence of turbulent movements in the cause of soarability. Besides the facts here mentioned other facts will be brought forward in Chapter XX. that throw doubt on this explanation. (See Wegener, "Ueber Turbulente Bewegungen in der Atmosphaere," *Meteorologische Zeitschrift*, February, 1912, Part 2, Vol. XXIX., page 49.)

CHAPTER IV.

PRELIMINARY ACCOUNT OF DIRECTIVE MOVEMENTS IN GLIDING FLIGHT.

On rare occasions I have seen a stork circling in company with the more common soaring birds. This bird, when soaring, carries its head and neck outstretched in front and its legs stretched out behind so that the distance from head to foot is nearly as great as the total span of its wings. With vultures, on the other hand, neither the head nor tail forms a conspicuous object during soaring flight. Vultures soar with their long necks coiled in such a way that the head scarcely projects beyond the line of the front of the wings. The tail is small in proportion to the area of the wings. In a vulture that I measured having a span of 82in., the tail was 8in. long and 4in. wide when furled.

In cranes, storks, adjutants, and similar birds in which the head extends for a distance beyond the line of the front edge of the wings, the head is kept perfectly still, except occasionally during descent. There is no reason for suspecting that movements of the head and neck are used for steering. By "steering" I intend to refer to voluntary movements to right and left in the horizontal plane.

In the cases of vultures and cheels, movements of the head frequently occur. But careful examination shows that these movements have nothing to do with steering. A cheel may turn its head to one side and

still remain travelling in a straight line. Or a cheel having some food in its claws may lower its head, and bringing forward its feet, may tear and eat the food without interruption of its gliding flight. When vultures are starting their circling flight it is interesting to notice how little they appear to attend to what they are doing. Turning their heads to one side or the other as they watch other birds, or look at the ground below them seems to have no effect on the regularity of their course.

I purpose describing my observations relating to the functions of the tail in a later chapter, and shall then show that adjustments of this organ are not used to produce steering movements in the horizontal plane.

A statement has recently appeared in a popular paper to the effect that birds can steer by lowering one foot or the other. This opinion does not appear to be based on any serious observation. As I shall afterwards show, vultures do lower their feet when preparing to descend in certain cases. Sometimes one foot may be lowered a short time before the other. Vultures can, and usually do, steer from side to side without lowering their feet, and if they do lower one foot any steering effect produced is certainly infinitesimal. Hanging down the feet may act as a brake, but as I shall explain later, this is not the most important method of checking speed that is used in descent.

I first obtained a clue to the nature of steering movements by observing the flight of the black vulture, in which bird these movements are commonly of greater extent than in other species. By practice my powers of observation have increased, so that I am able to observe steering movements in other species of birds.

For obvious reasons the larger birds are the most suitable for making these rather difficult observations. But I have on one occasion been able to see the movement that I shall describe in Chapter VI. as the "depression" in the wing of the green parrot, a very fast-flying bird of comparatively small size.

If a black vulture is watched when ease-gliding occasionally the tip of one wing will be seen to be momentarily depressed downwards and then raised at once to its original position. The range of movement may be 3in. or 4in. This dipping downwards of the wing-tip occurs at about the same speed as one might turn over and turn back the page of a book. After this movement has been completed the bird begins to turn in its course towards the side of the wing-tip that was depressed. After the movement there is almost time to formulate in words which way the bird is going to turn before the commencement of the turn can be recognised. That is to say there is the appearance of a latent period between the movement and the resulting steering action. In my notes I originally described this movement as a dipping downwards of the wing-tip. This phrase was soon abbreviated to "dip," by which term I propose to refer to the movement in future.

It is necessary to consider how the "dip" is brought about. The first possibility that suggested itself to me was that it was caused by some of the intrinsic muscles of the wing. But on examining the wing of a dead bird it appeared to me that the range of possible movement of the carpal joint was less than my observations had led me to expect. It then occurred to me that perhaps what really happened was that the whole

of the wing was rotated until the air pressed on its upper surface instead of on its under surface. It is conceivable that should this be the case the quill feathers would thereby be depressed, and so cause the appearance of the dip, especially as it is likely that the less-supported quill feathers of the wing-tip would thereby be most affected.

In order to decide between these two possibilities, I dissected the wing of a black vulture, and found that neither of the above-suggested explanations is an adequate statement of the facts of the case.

None of the intrinsic muscles of the wing have any power of making a dip movement by direct action. But on the under side of the ulna I found three muscles that have the power of rotating the front edge of the outer part of the wing. Supposing the wing is extended horizontally, then, if these three muscles come into action, the front edge of the wing-tip becomes depressed. That is to say the wing-tip is rotated round the axis of the wing. The rotation is in such a direction that the air ceases to press on the under side of the wing-tip feathers. Instead it presses, or tends to press, on their upper surfaces. Hence the tips of these feathers are bent downwards producing the appearance of the dip movement. From the dorsal aspect of the wing two muscles may be seen that have the power of rotating the front edge of the wing-tip in the opposite direction. These muscles come into action at the end of a dip movement to return the wing-tip to its original position.¹

¹ Rotation in such a direction that the front edge of the wing-tip goes down, and the hinder edge up, may be described as "rotation downwards." Rotation of the wing-tip in the opposite direction may be described as "rotation upwards."

I have also found these muscles in the wings of the common vulture, the Adjutant (*Leptoptilus dubius*), the Sarus (*Grus antigone*), and other birds.

Fig. 14 represents diagrammatically the structure of the wing-tip: A B is the axis of the wing: I. to X. are the large wing-tip feathers, usually known as the primary quills. Of these, I. to IV. are attached to the phalangeal bones C, forming therewith a practically

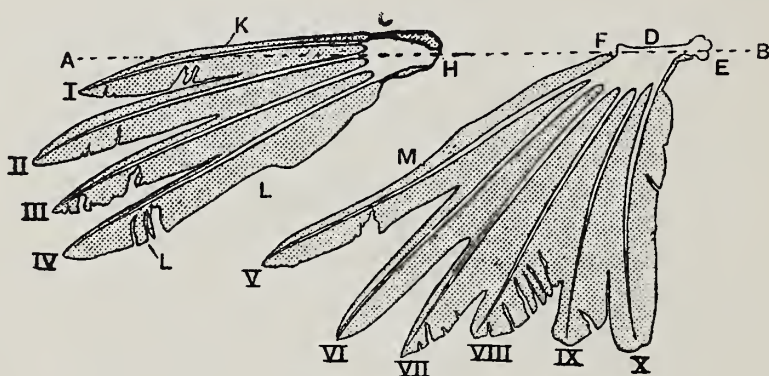


FIG. 14.

Structure of wing-tip of vulture. A B.—Axis of wing. C K L.—Digital quill mass, consisting of first four primary quills, I., II., III., IV., which form an almost solid mass with the phalangeal bone mass C. The digital quill mass is articulated at H to the point F of the metacarpal quill mass M D. This latter consists of the fused metacarpal bones D, to which are firmly attached the remaining primary quills V., VI., VII., VIII., IX., and X. These quills may conveniently be termed metacarpal quills. The metacarpal quill mass is articulated at E, the carpal joint, to the main part of the wing. For the sake of clearness, the alula or bastard wing has been omitted.

solid mass. These first four quills may conveniently be described as the “digital quills.” The remaining primary quills V. to X. are similarly attached to the metacarpal bone D. These quills may therefore be described as the “metacarpal quills.” The point of attachment of the metacarpal quill mass to the rest of the wing is indicated at E. The digital quill mass is articulated at the point H to the point F of the metacarpal mass. That is to say, E is the carpal joint, and

H and H represent the metacarpal joint. If the wing is extended horizontally, movement at these two joints may take place in the horizontal plane by the action of various flexor and extensor muscles. In birds there is no muscle that can bend the wing-tip downwards by direct action. As I shall show in a later chapter, in bats there is such a muscle, which can bend the wing downwards at the carpal joint, and is used in flapping flight at the end of each downstroke. In birds, any appearance of bending downwards at the carpal joint can only be due to indirect causes, such as pressure of air on the upper surface of the wing. Slight rotation round the axis of the wing can occur at the carpal and metacarpal joint, and is so produced by the muscles that I am about to describe.

Let us suppose that the diagram fig. 14 represents the two parts of the wing-tip of the left wing as seen from above. The arrangement is such that the inner feathers overlap the outer feathers.¹ That is to say, for instance, the edge M of quill V. overlaps the edge L of quill IV. In the case of the common vulture, when making a dip movement of limited extent, a gap of about 1 in. may be seen to occur momentarily between the points M and L. Therefore the rotation of the point K downwards does not immediately result in L being elevated. On the contrary, owing to the rotation, the whole of the digital mass ceases to be pushed up by the air, and therefore becomes depressed. If a small dip of this nature passes on into a full dip, then this gap closes up, and there is an appearance of the hinder ends of the quills becoming elevated. My diary con-

¹ In the complete wing the bases of the quill feathers are covered by smaller feathers known as "coverts."

tains several instances of observation of this "digital quill gap" in several species of birds. I have observed it in circling, ease-gliding, and in the gliding periods of flap-gliding.

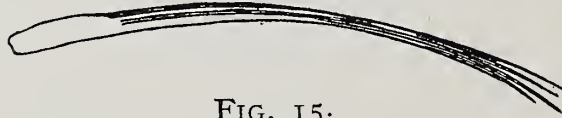


FIG. 15.

View from in front of phalangeal quills.

This dip movement of limited range, in which the digital mass only is moved, I propose to term the "half-dip." During the half-dip, owing to the rotation, air ceases to press on the under surface of the feathers. But rotation is not carried far enough for air to press on the upper surface of the quills. Hence, during the half-dip, the feathers being relieved from air pressure, whether from above or below, take on their natural curvature, as shown in fig. 15. A half-dip movement causes a steering effect in the same direction as a full dip,

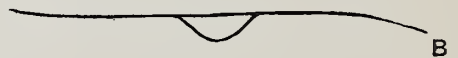
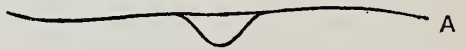
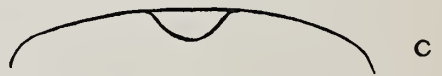


FIG. 16.—End-on view of bird.

A. During half-dip.

B. During full-dip.

C. During double-dip.



but to a less extent (fig. 16). I have been able to see this steering effect on several occasions, but perhaps more often than not the effect is too small to be detected.

It may be suggested that during a dip the air acts as a drag by pressing the upper surface of the quills. This suggestion is an easy explanation of the steering effect. But the phenomenon of the half-dip suggests that it is not sufficient, and facts to be described in later chapters will be found to prove that a more deep-seated action is involved.

The chief muscles concerned in rotating the wing-tip are shown in fig. 17. This is a diagrammatic view of the under side of the wing, in which various muscles not concerned with wing-tip rotation have been removed for the sake of clearness. The following are the names that I propose for the muscles, with a short description :

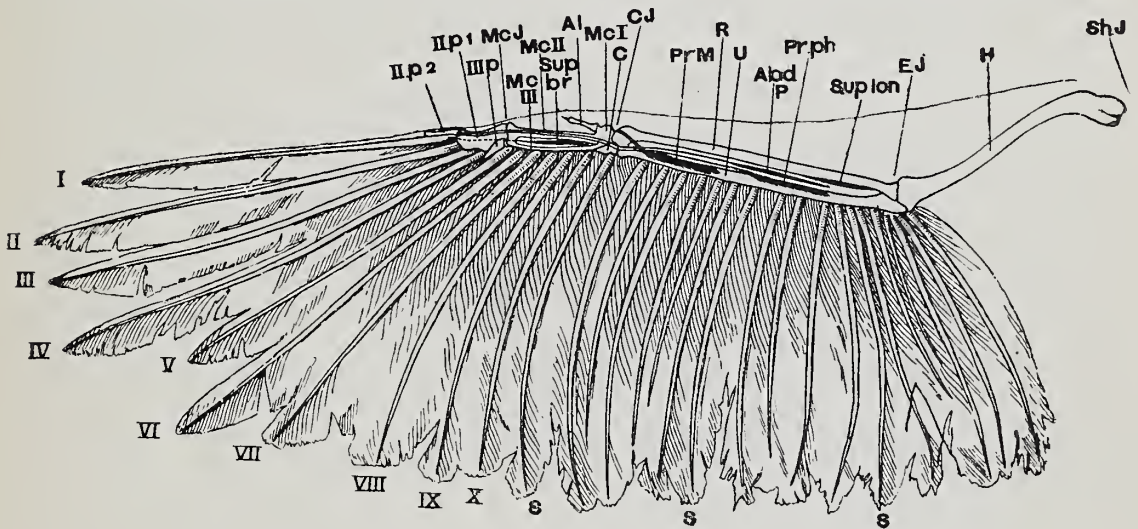


FIG. 17.

Dissection of right wing of Common Vulture (*Pseudogyps bengalensis*) seen from below, showing muscles concerned in rotation of wing-tip.

ShJ.	Shoulder joint.	IIp ² .	Terminal or second phalanx of Digit II.
H.	Humerus.	IIIp.	Phalanx of Digit III.
EJ.	Elbow joint.	Sup lon.	Supinator longus muscle
R.	Radius.	Pr ph.	Pronator phalangis muscle
U.	Ulna.	Abd P.	Abductor pinnæ muscle.
CJ.	Carpal joint.	Pr M.	Pronator metacarpi muscle
C.	Carpal bone.	Sup br.	Supinator brevis.
McI.	Metacarpal of Digit I.	I., II., III., IV.	Digital quills.
McII.	Metacarpal of Digit II.	V., VI., VII., VIII., IX., X.	Metacarpal quills.
McIII.	Metacarpal of Digit III.	S., S., S.	Secondary quills.
Al.	Alula or Digit I.		
IIp ¹ .	Basal or first phalanx of Digit II.		

I. *Pronator phalangis*. This muscle arises from near the base of the ulna. Its tendon is inserted on the base of the terminal phalanx of digit II. It may be explained that the wing of the bird contains the remains of three digits. Digit I. is known as the alula or bastard wing. The diagram shows phalanges of two other

digits. The metacarpals of these three digits are fused into one mass.

2. *Abductor pinnæ*. This muscle arises from a tendinous band or fascia that connects the elbow and carpal joints. This band is omitted from the diagram for the sake of clearness. It is inserted on the outer side of the terminal phalanx of digit II. Pulling the tendon of this muscle has a slight effect in rotating down (or pronating) the wing-tip, but also tends to advance the digital quills.

3. *Pronator metacarpi*. This muscle arises from the under surface of the distal (*i.e.*, outermost) part of the ulna. Its tendon passes in a curved course over the carpal joint, and is inserted on to the base of the metacarpal of digit I.

4. *Supinator longus*. This muscle arises from the external condyle of the humerus. Its tendon (not shown in the diagram) is inserted on the terminal phalanx of digit II. A small branch of its tendon is inserted into the alula. The action of this muscle is to rotate the front edge of the wing-tip upwards, that is to say, to return it to its original position after a dip movement.¹

5. *Supinator brevis* is a short supinator muscle lying in the hollow of the metacarpal bone mass.²

In order to see the rotation of the wing-tip produced by the above muscles, a large bird should be taken. The wing should be clamped at the humerus. A tape should be tied to the fifth primary quill and stretched so as to extend the wing. Tapes should be

¹ The branch of the *Supinator longus* tendon to the alula was missing in one and present as a fine translucent band of tissue in the other of two specimens of the Sarus (*Grus antigone*) that I have dissected.

² It is probable that the action of the *Supinator brevis* is to lock together the digital and metacarpal quill masses. When this muscle is thus in action, a pull from the pronator tendons would rotate down not only the digital mass but also the metacarpal mass.

attached to the tendons of the *Supinator longus*, the *Pronator phalangis*, and the *Abductor pinnæ*. On pulling the first-named tendon the wing-tip will be seen to be rotated upwards. On pulling the other tendons the wing-tip rotates in the reverse direction. The bird should be freshly killed, and only a small part of the basal portions of the tendons should be dissected out.

A second kind of steering action also occurs. This is visible as a momentary depression of the whole wing. The result is that the bird turns towards the side of the wing that is depressed. I propose to bring forward evidence bearing on the question of the nature of the depression movement in Chapter VI.

Perhaps more often than not in the smaller soaring birds, and sometimes in larger soaring birds, the dip is combined in one movement with wing depression of greater or less extent.

The following account of a dissection of the Dusky Horned Owl (*Bubo coromanda*) will be of interest :

The bird was of $43\frac{1}{2}$ in. span, and the loading was 1.04 lb. I found that the pronator and supinator muscles had no power of rotating the wing-tip. They appeared to aid in extending the wing, and could also advance the alula. A branch of the *Pronator phalangis* tendon was supplied to the alula, and the main tendon of this muscle was inserted into the base of the end phalanx of digit II. The tendon of the *Abductor pinnæ* was inserted into the distal end of the first phalanx of digit II., and also into the cartilage of the joint between the two phalanges of this digit. That is to say, the abductor tendon, as compared with the condition in

soaring birds, is degenerated, and destitute of what may be regarded as its original function.¹

In three species of heron I found, by dissection, that the power of wing-tip rotation possessed by the long pronator and supinator muscles was less than is possessed by the corresponding muscles of vultures. Cranes and adjutants have the power of wing-tip rotation as well developed as in vultures.

When in a later chapter we come to examine the functions of the wing-tip more minutely, the reason will be apparent why a power of wing-tip rotation is required for soaring flight, and is less necessary for birds that do not take energy from the air in this way.

The above is a preliminary description of the method employed by soaring birds for steering to left or right in the horizontal plane. In other words, we have outlined the method employed for turning to and fro round the dorso-ventral axis. But the bird can also direct its course either upwards or downwards. That is to say, it can rotate to and fro round its transverse axis. The bird may be regarded as having a third, namely the longitudinal, axis. By rotating to and fro round this third axis the amount of canting or banking is increased or decreased.

¹ The muscles of the forearms of birds have been described by Gadow in Bronn's "Klassen und Ordnungen des Thier-Reichs, Aves." They have been further described by Beddard ("The Structure and Classification of Birds," Longman, Green, and Co., 1898). As these authors make no mention of rotation of the wing-tip, and as my names were chosen with reference to the functions, it is desirable that the names given in the text should be retained. Using the sequence in the list in the text, the names employed by Gadow for the muscles in question are: (1) *Flexor digitorum profundus*, (2) *Flexor digitorum sublimis*, (3) *Ulni-metacarpalis ventralis*, (4) *Extensor digitorum communis*, (5) *Interosseus dorsalis*. It is interesting to notice that many of the earliest fossil birds, possibly and perhaps probably, had the power of soaring flight. For instance, the cretaceous formation has yielded *Ichthyornis* (allied to gulls), *Scaniornis* (allied to the flamingo), and *Graculavus* (a cormorant allied to pelicans and frigate birds). The Miocene strata have yielded remains of a bird supposed to belong to the same genus as the Adjutant (*Leptoptilus*). I have collected facts and opinions relating to this subject in a paper entitled "The Development of Animal Flight," published in the *Aeronautical Journal* for January, 1912, page 186. Digits I. and II. of the vulture are furnished with small claws, which are vestiges of the functional claws present in its reptilian ancestors. The claw of digit I. is shown in fig. 17. The claw of digit II. is too small for representation in this diagram. It would be an interesting research to investigate the power of wing-tip rotation in different classes of birds.

I now propose to bring forward evidence relating to one of the methods employed for rotation round the transverse axis.

A tendency to dive head downwards, or else losing speed to glide backwards and descend tail foremost, has been shown by various gliders and aeroplanes.

Soaring birds behave as if free of this tendency. But they can dive voluntarily when they wish to descend from a height at speed. A study of the method by which they check their speed when thus diving will be found to be of interest and to lead to the suggestion that they have a perfect method of preserving their longitudinal stability far superior to the use of elevators or horizontal rudders as seen on aeroplanes.

The following extracts from my diary illustrate the general phenomena shown by birds when diving:

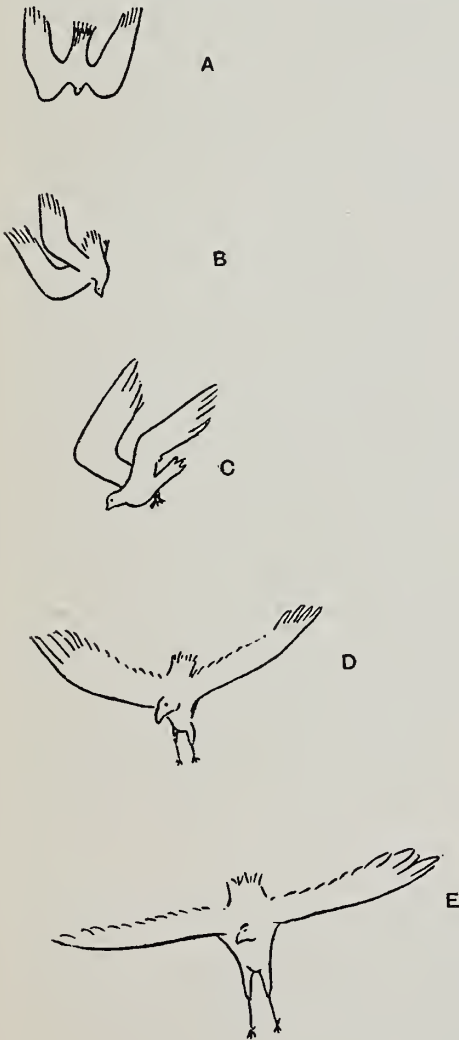
February 14th, 1910. At 3.36.—A light west wind and a few isolated cumulus clouds. At the time of commencing my observations only one vulture was visible. It was flex-gliding. Its height was measured with the telemeter and found to be 700 metres. While watching it I noticed that its speed was greater than usual, and I at once made a measurement. It was found to be 40 metres per second—that is to say, 89 miles an hour. It was then seen to be diving downwards, its track making an angle of perhaps 20° or 30° with the vertical. After I had made the measurement, its speed increased rapidly and greatly. At a height of about 100 metres above the earth, it suddenly checked its dive, swerving somewhat from its course while so doing. The bird was then seen to be descending at moderate speed with its wings extended in the horizontal plane and slightly flexed. Its body and legs were hanging down below the level of the plane of the wings, and as it descended it was swaying to and fro like a parachute till it reached the earth. Within one or two minutes about thirty other vultures dived and landed in the same way. Then a vulture was seen which after its dive, and after it had commenced "parachuting," drew up its legs and flex-glided off, having apparently changed its mind. The vultures that had settled rose at 3.45, circling with flapping. Above 50 metres height they circled without flapping. They drifted to leeward, and passed me at about 200 metres height. The "windward dip" was seen in several. Also half dips of the outside wing on the windward side of the circles. Above 200 metres height the vultures gained height rapidly.

Though I was able to follow several of the diving birds with the binocular, it was quite impossible for me to see the method by which their speed when diving was so suddenly decreased. To be able to see how this is done it is necessary to be standing near the carrion, so that the birds are seen approaching. Thus having an end-on view of their track more can be observed than when they are diving at a speed of probably more than 100 miles an hour across the field of view. I had seen some years ago the actual adjustment used for checking speed when diving. In view of my increased acquaintance with the subject it was desirable for me to see these movements again. A fortunate chance gave me this opportunity. The following description is from my diary :

20th March, 1910. At 5.0.—I arrived at Futteypur-Sikri just as the body of a leopard, that someone had shot and skinned, had been thrown over the edge of the hill a few yards away from the terrace of the dawk bungalow. Vultures were descending. For the most part they came from a distance, gliding downwards at a small angle of descent. One was watched nearly overhead diving downwards. When about 200 metres up it placed its wings, still flexed, in the dihedrally-up position, so that the two wings made with one another a dihedral angle of between 90° and 100° . The bird also began to extend its legs; consequently it rotated in the air round its transverse axis, so that instead of descending head first, it descended legs first. As, in consequence, the speed decreased, the dihedral angle of the wings diminished. When near my level the wings were nearly flat—that is to say, extended horizontally, with no dihedral angle. The legs and also the body were hanging downwards below the level of the wings. All the birds as they descended glided to leeward of the dead leopard, so that when landing they were gliding up wind. The wind was west and very light, slightly moving the leaves of the trees. (How these birds knew the direction of the wind is a question more easily asked than answered.) The birds that arrived flex-gliding from a distance began to drop their legs and allow their bodies to hang down when about 50 metres up, and when from 50 to 100 metres to leeward of the leopard. The “alula” was seen to be advanced in every vulture observed. In one or two instances the alula of one wing was seen to be suddenly rotated upwards. In spite of my best endeavour, it was impossible for me to observe whether this rotation affected both alulae at the same time. The observed movement of the alula must have been over 2 centimetres of its front edge. One vulture, when gliding down,

suddenly slightly increased the flexing of both wings simultaneously. This produced an immediate drop of several feet, nearly vertically, obviously with the intention of getting to the ground without overshooting the mark. The drop was checked by renewed extension of the wings.

The important point in this description is the fact that the diving vulture placed its wings in the dihedrally-



up position to cause rotation round the transverse axis. On other occasions I have seen black vultures and cheels, when playing together in the air, make short dives, which were checked by placing the wings in the dihedrally-up position.

Fig. 18 shows diagrammatically the changes in the disposition of the wings that result in checking the speed of diving. The explanation of the rotation is obvious. When the wings are placed dihedrally-up, as at B, the inertia of the bird acts through the centre of gravity, pulling the bird directly downwards or

FIG. 18.

A vulture diving and checking speed.

A. Position assumed in diving.

B. Wings, still flexed, placed in dihedrally-up position.

Owing to the inertia acting through the centre of gravity and the resistance of the wing-tips forming a couple, the bird rotates to the position shown at C. In this position, instead of descending head first, it is descending legs first, with greatly increased resistance.

nearly directly downwards. The resistance of the wings must be acting in the opposite direction. The two forces do not act in the same straight line.

Hence there must be a couple that rotates the bird to the position shown at C.

I will now consider the effect of changes in the dihedral angle. The change from the dihedrally-up to the dihedrally-down positions can often be seen in cheels, though in these birds it is usually not very great in extent. One of the first things I noticed on beginning my observations on cheels was that the dihedrally-up position is seen in circling, especially on the up-wind side of the circle. I also saw that it was assumed at the end of a horizontal glide, and that it immediately resulted in a gain of height. I learnt to associate the dihedrally-down position with loss of height and increase of speed. I once saw a cheel gaining height in several successive circles, with its wings, so far as I could see, in the dihedrally-up position all round the circle. Then, without gain of height, it described a circle, with the wings either flat or slightly dihedrally-down. Then it made a long glide in a straight line, descending gradually, with the wings dihedrally-down and with clearly seen increase of speed.

Towards sunset, when the air near the earth usually loses its power of permitting soaring flight, soaring birds may be seen returning to roost by flap-gliding flight, that is to say, by flapping flight alternating with periods of gliding. Each glide may last from 5 to 20 seconds; the periods of flapping may be 5 seconds or less. During the glide the bird appears to travel horizontally. Sometimes there is a slight loss of height at the commencement of the glide, and a slight gain of height at the end of the glide, so there are no grounds for assuming that speed is maintained at the expense of height.

On the other hand, in soaring birds when flap-gliding in unsoarable air height is maintained at the expense of speed. In other words, during the glide, speed is being lost, and the angle of incidence is being gradually increased by increase of the dihedral angle of the wings.¹ In the case of cheels, the wings are flat or slightly dihedrally-down, but towards the end of the glide the wings may be seen to be dihedrally-up. This change of disposition may be seen to be accompanied by a slight gain of height and immediately after this gain of height flapping recommences. In the case of vultures, the wings may be either flat or dihedrally-up. The flat disposition is adopted when the bird is about to settle. It may rarely be seen also under conditions that may be regarded as preparatory for flex-gliding. The dihedrally-up position appears to be adopted by vultures for continued flap-gliding flight. In the case of flying-foxes (*Pteropus medius*, a bat of 44in. to 51in. span), which occasionally may be seen in gliding flight for short distances, if the wings are held dihedrally-down there is loss of height and increase of speed. For gliding with less loss of height this species of bat keeps its wings "arched," that is to say, concave from side to side.

The correctness of the above suggestion that, in gliding, height is maintained at the expense of speed is proved by the following observation:

21st August, 1911, on Tundla Road, near Jharna Nullah. At 6.30.—A large number of adjutants, during more than half an hour, were flap-gliding in the direction of the river, presumably to spend the night on

¹ If the wing of a bird is regarded as a flat plane, then, in horizontal flight (in unsoarable air), this plane is slightly tilted up, so that the air strikes its lower surface, and hence has a lifting action. The angle between the plane and the direction of movement of the bird is known as the "angle of incidence." As a matter of fact, when the wings are fully extended they are not flat planes, but are hollow from before backwards. That is to say, they are slightly concave underneath, or in common parlance "cambered." That is to say, the angle of incidence, in this case, is the angle between the chord of the wing and the direction of motion. When gliding with a small angle of incidence, the centre of pressure does not coincide with the centre of area, but is situated some distance in advance of this point. Readers unacquainted with these terms would do well to consult some book on aeronautics.

a sandbank. They travelled at a height of less than 10 metres above the earth. The periods of flapping and gliding were each of only a few seconds duration. No vertical flaps occurred before the glides—that is to say, the wings on the down stroke were flapped downwards and forwards; there was no vertical flap before the glide, as sometimes occurs. In all cases observed, probably more than fifty birds, an increase in the angle of incidence was seen to occur during each glide. The angle of incidence was at a minimum immediately after the flapping. It gradually, and, I think, continually, increased to reach its maximum just before the next period of flapping. This was easily observed. In three cases, in addition, a gradual increase in the dihedrally-up angle of the wings was seen to take place. In one case I saw slight oscillation round the longitudinal axis, apparently as a single to-and-fro movement, immediately after flapping. The range of movement of the wing-tip was certainly less than 2in., and may have been about an inch. Previously, on the same day at Jharna Nullah, I had observed this oscillation in other species of birds. It is difficult to see. During the down-stroke the adjutant makes a whistling swishing sound, reminding one of the sound made by telegraph wires vibrating in a wind. This sound varies in amount. In two cases I was also able to hear a faint whistling sound during the gliding period. This resembled the sound one would expect to be made by air rushing into or out of a cavity. (I have frequently heard this “glide-whistle” since. It may possibly have to do with change of volume of the air sacs.)

Since making this observation I have seen the increase of the angle of incidence during the glide in other species of soaring birds.

Changes in the angle of incidence may also occur owing to changes in the nature of the air. If more air energy is available the bird may glide at higher speed with small angle of incidence. If less energy is available the bird glides at lower speed with a larger angle of incidence. In the following observation the presence of lateral instability (that is to say, a tendency to tilt over from side to side) and the absence of tail-jolting (that is to say, the absence of transverse axis instability) are signs that the air had a low degree of soarability, as will be further explained in a later chapter:

7th December, 1911, Jharna Nullah. At 3.35.—Wind shown to be south by movement of smoke. Occasional flapping of vultures at low levels. They showed slight lateral instability apparently most marked just after flapping. Cheels in steady flight without tail jolting. A brown

vulture flapping. The wing-tip feathers were seen to be less apart during the up-stroke than when gliding. This was seen in several flaps.

4.o.—Lateral instability now more marked, but still difficult to see. It was seen during the glide, besides just after flapping. Cheels showed single-wing depressions (a sign of dorso-ventral axis instability). This form of instability is usually shown by the lighter birds under those atmospheric conditions that cause the heavier birds to show lateral instability. A vulture that had just been flapping was watched gliding in a straight line for several hundred metres. While so doing it showed three or four gradual changes of the angle of incidence. These were well marked. Usually an increase in the angle of incidence in vultures is a sign that the bird is about to flap. In the present case, the changes were probably due to its getting into patches of more or less soarable air. The phenomenon had no similarity to tail-jolting.

If a cheel wishes to glide downwards it places its wings in the dihedrally-down position. If it wishes to increase the steepness of its descent it elevates the tail, which is closely furled. If the tail feathers have been cut off, the posterior portion of the body can be seen to be elevated, that is to say, there is no reason for believing that the elevation of the tail acts by any effect of the air currents on its surface. It obviously must act by further increasing the distance between the centre of gravity and the centre of resistance of the wings. I have also seen elevation of the tail for gliding downwards in vultures and in several species of smaller birds.

In the gliding flight of the swift and other kinds of birds an increase of speed is initiated by a sudden elevation of the furled tail and the wings being placed momentarily in a dihedrally-down position.

In fig. 19 is shown the outline of a bird with wings in the dihedrally-down position. Let us suppose it is gliding forward horizontally in unsoarable air. The momentum of the bird may be regarded as a force acting at the centre of gravity, and tending to pull the bird forwards, as shown at A. Another force acting on the

bird is the resistance. This tends to pull the bird backwards. The resistance of the body of the bird to forward movement is constant in its position as regards the centre of gravity. The resistance of the wings to movement forward varies in its relation to the centre of

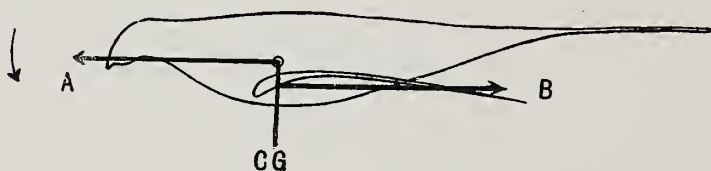


FIG. 19.

Outline of cheel with wings dihedrally-down to an extreme degree. The centre of resistance of the wing to forward movement is below the position of the centre of gravity C.G. Hence there is a couple tending to rotate the bird downwards (*i.e.*, head down, tail up) round the transverse axis.

gravity as the wings are raised or lowered. When the wings are dihedrally-down to an extreme degree, as shown in fig. 19, their resistance acts as a force B on a lower level than the centre of gravity. Hence there is a couple between A and B that tends to rotate the

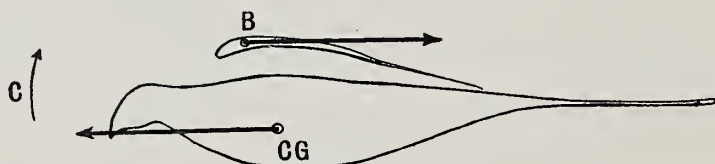


FIG. 20.

Diagrammatic outline of cheel with wings dihedrally-up. The inertia of the bird acts through the centre of gravity at C.G. The resistance to forward motion of the wing-tips acts at B. The result is a couple tending to rotate the bird upwards round its transverse axis, as indicated by the arrow C.

bird round its transverse axis. The rotation is such that the head tends to go down and the tail tends to go up. This may be described as "rotation downwards."

Conversely in fig. 20 a bird is shown with the wings dihedrally-up. In this case there is a couple C in the opposite direction, and tending to rotate the bird upwards round its transverse axis. That is to say, the

rotation is such that the head goes up and the tail goes down.

If the bird is gliding in soarable air, and taking energy from this soarable air, the wings are subject to tractive effort. In this case, if the wings are fully extended, the wing tips furnish the necessary resistance to enable the bird to rotate round the transverse axis by changes of the dihedral angle.¹

Cheels when ease-gliding or flex-gliding frequently show slight upward jolts of the tail. These jolts may occur at intervals of a second or less. Tail-jolting is apt to be associated with disturbed weather. It is seen at a maximum in the highly soarable air of dust-storms, where the range of movement of the end of the tail may be as much as an inch or more. In such cases each upward jolt is seen to be accompanied by the wings being placed in the dihedrally-down position. Consequently each tail-jolt must tend to rotate the bird downwards round its transverse axis. The tail-jolt is a delicate sign of transverse axis instability. Tail-jolting occurs in different species of vultures, but owing to the relatively smaller size of the tail in these birds, and also owing to the fact that they usually glide at higher levels than the cheel, the adjustment in vultures is less easy to see. In the case of cheels that have lost their tails, tail-jolting is represented by energetic up and down movements of the hinder end of the body.

Thus it appears that birds can alter the distance between the centre of gravity and the centre of resistance of the wings. They do this by changes in the

¹ It is probable that in slow flex-gliding the wing tips also furnish the necessary resistance, and hence the above explanation applies to the double dip movement used in changing from slow to fast flex-gliding. But the matter is not entirely clear, and will be referred to in a later chapter. Another kind of transverse axis rotation that results in a change of course will be described later.

disposition of the tail and by change in the dihedral angle of the wings. In a later chapter I shall have to describe another method of producing rotation round the transverse axis.

The cases of change in the dihedral angle of the wings hitherto described are easy to understand. I now have to describe a frequently observed change in the dihedral angle of the wings that I propose to term the "double dip," and that cannot be fully explained in the light of existing knowledge. At the commencement of a flex-glide and during a flex-glide it sometimes happens that both wings are momentarily depressed to an extreme degree. The speed at which the wings are depressed and returned to their normal position is a little less than the speed of flapping. From this description one would expect the double dip to produce a strong rotation round the transverse axis. This I have observed in several cases. One would also expect this rotation to produce a dive downwards. The double dip is usually seen to be immediately followed by a sudden increase of speed. One would expect that the short dive downwards is the cause of the increase of speed. But if the increase of speed is caused by the dive, then the dive must amount to several metres. That is to say, the dive is not one that could be easily overlooked. But as a matter of fact I have only once observed a dive, which was of small extent, and in this case the bird was already gliding downwards. As will be seen from the following observations in certain cases I have observed a double dip from so short a distance that I could observe changes in the position of individual feathers. That is to say, there is good reason for asserting that if a dive is

produced by a double dip it is too small to explain the observed increase of speed. The following are examples of my observations :

13th February, 1910. At 12.36.—A black vulture was seen end-on as it was beginning a flex-glide in my direction. The double dip was seen to be accompanied by and apparently to cause a tilting of the body, so that during the dip its long axis pointed downwards at an angle of about 45° .

17th June, 1910, at Ballia Ravine (Naini Tal). At 2.50.—Strong sunshine. A vulture seen descending. The alulæ were extended early. Double dip seen while legs were hanging down.

19th June, 1910, at Ballia Ravine. At 12.20.—A brown vulture noticed ease-gliding down valley. Both wing-tips were momentarily depressed together, presumably for increasing speed.

20th July, 1910, at Jharna Nullah. 5.52.—An adjutant flex-gliding slowly descended to about 80 metres height above the ground. Then it dropped to earth suddenly to steal some meat that a cheel was eating. It commenced this dropping with a strongly marked double dip with rotation of body. Immediately after the double dip the wings were seen to be extended and arched. (Arching is a sign of decrease of the angle of incidence, as will be shown later.) The wind at the time was light, but enough to move leaves.

28th August, 1910. At 11.40.—A vulture flex-gliding with wings very slightly flexed, seen to make a double dip. During the up-stroke of this double dip the wings were seen to assume extra flexing. The speed was seen to be increased immediately after the double dip.

2nd October, 1910. At 4.0.—A black vulture seen at a height of perhaps 300 metres lift-gliding. Its wings were slightly dihedrally-up and slightly advanced. It showed slight lateral instability. After lift-gliding for about 200 metres, it began circling. During several circles one small windward dip only was seen, and in two circles I saw retirement of outside wing-tip. Then it again lift-glided up-wind for about 200 metres, and then began flex-gliding with a double dip. In a second or two the double dip was repeated. After the first double dip the speed was seen to be suddenly and distinctly increased.

15th June, 1911, at Ballia Ravine. At 3.15.—A brown vulture near me going down the valley showed a double dip. During this movement the wing rotation was clearly seen. The free ends of the secondaries went up, while the front edge of the wing and the wing-tips went down. (My recollection is that during the up-stroke of this double dip the plane of the wing was so far rotated that it formed an angle with the vertical of only about 10° to 20° .)

A similar observation was made on the 25th June.

10th November, 1910. At 9.0.—A cheel circling with occasional flapping. It made a double dip, and ease-glided off. At moment of double dip the secondaries were relaxed.

9.5.—Cheels in steady flight. Haze. Wind shown to be west by smoke.

17th April, 1910. At 4.36.—A brown vulture showed rotation round transverse axis at moment of double dip. During the dip the alula seemed to stand out.

30th March, 1912. At 1.0.—A black vulture gliding downwards at a small angle with the horizon. It made a double dip. This produced rotation of body round transverse axis, and a dive of 1ft. or 2ft.

Certain eagles, when playing in the air, sometimes make a swoop which is first in a downward and then in an upward direction. At the end of the swoop, when they have reached the highest point, they make a double dip. This causes both rotation round the transverse axis and also a dive. During this dive speed is seen to increase gradually owing to the action of gravity. There is no sudden increase of speed as is seen to follow the double dips of the more efficient soaring birds. This double dip of eagles occurs at a time when speed ahead is slight. The double dips of vultures that occur in soarable air and that cause sudden increase of speed without a dive only occur when the bird has high speed ahead. A further discussion of the double dip will be found in Chapter XI. It is obvious that an understanding of this adjustment might be expected to throw some light on the nature of the unknown process by which the soaring bird gets energy from soarable air. It appears to be a fact that the adjustment, in some unknown way, initiates an increased rate of consumption of air energy.

CHAPTER V.

ON CONDITIONS AFFECTING SUN SOARABILITY.

In an earlier chapter I stated that there is a gradual increase in the soarability of the air during the morning, as shown by the fact that different species of birds commence circling at different times.

Some of my observations are summarised in the following table. The figures are the number of minutes that elapsed between the first circling of cheels and the first circling of the different species of birds mentioned :

	February.								Mar.	Apr.
	6th	13th	14th	15th	19th	20th	23rd	24th	10th	11th
White scavengers	34	41	15	58	38	37	27	68	26	11
Common vultures	41	47	54	62	38	74	48	75	35	32
Black vultures ..	70	79	68	62	65	41	48	75	50	51

That is to say, on February 6th, 1910, for instance, white scavenger vultures began to circle 34 minutes after cheels had commenced circling. Common vultures began 41 minutes and black vultures 70 minutes after the first circling of cheels.

Always without exception the lightest bird, namely the cheel, is the first to start. Its load is .55 lb. per square foot of wing area.

The cheel is usually followed at an interval of between 20 and 40 minutes by the white scavenger vulture, whose load is .87 lb. per square foot.

The common white-backed vulture, having a load of 1.13 lb. per square foot, may be expected to start between 40 and 60 minutes after the cheel.

The black vulture has a load of 1.23 lb. per square foot; usually starts between 60 and 80 minutes after the cheels.

The adjutant bird (*Leptoptilus dubius*) has a load of 1.54 lb. per square foot of wing area. I have observed it starting about 120 minutes after cheels. Though adjutant birds usually emigrate from India after the rainy season, about half a dozen remain in Agra during the cold weather. On several occasions, at Jharna Nullah, during the colder months I have noticed that the soarability of the air was not sufficient to support the circling of adjutants. Either they remained settled, or, if they commenced circling for a few minutes in the middle of the day, they soon found occasional flaps were necessary to keep them aloft, and presently returned to earth.

Judging from a few observations, cranes appear to start some time after black vultures. I have not yet had an opportunity of measuring a crane (*Grus communis*), but I have made measurements of an allied species, namely, the sarus (*Grus antigone*). Its load was found to be 1.66 lb. per square foot of wing area. The flight of this bird is usually confined to flapping at a height of only 3 or 4 metres above the level of the ground. Occasionally however it circles to immense heights, but only in the middle of the day and in the hotter months of the year.¹

Thus the times at which different species of birds commence circling furnish a proof of the gradual development of morning soarability.

¹ Major Dickinson, I.M.S., tells me he has observed saruses on many occasions at about two o'clock in the day at Deesa, in Gujerat, circling at great heights. Occasionally they were at such a height as only to be visible with a binocular. Colonel Sutherland, I.M.S., has observed saruses circling at a height in the Central Provinces in the afternoon. In each case these observations relate to the hot weather months.

An interval always occurs between the time of commencement of circling and the time of commencement of flex-gliding. Also slow flex-gliding begins before fast flex-gliding.

The following extract from my diary is an interesting case, showing the interval between the air being suitable for circling and its becoming suitable for flex-gliding of the same species of bird :

April 11th, 1910. At 8.15.—Widespread circling of cheels began.

8.16.—Dihedrally-up position of wings first seen in a cheel, one at low level.

8.26.—Scavengers starting and circling.

8.42.—Cheels circling at high level still had wings dihedrally-down.

8.47.—A large vulture circling.

8.51.—Three more vultures starting and circling.

8.56.—During the last five minutes thirty-six vultures were seen flap-gliding to leeward, all rather low down (probably at a height of about 100 metres).

8.59.—Thirteen more vultures flap-gliding to leeward.

9.1.—Twenty more flap-gliding to leeward.

9.3.—Nine more not flap-gliding, but rapidly flex-gliding to leeward.

9.5.—Four more flex-gliding to leeward.

9.6.—Black vulture starting. Wind west, strong enough to move smaller branches, but showed a tendency to drop.

Though I described these vultures as “rapidly flex-gliding” to leeward, it is probable that they were “slow flex-gliding.” Their flight may have appeared rapid because they were unusually low down, and because they were travelling with the wind.

I have never seen anything like this phenomenon before. The vultures nearly all started from a point out of sight to windward, and went to some point out of sight to leeward. They must have commenced gliding before they had time to circle to any great height. Thus they can scarcely have been in a position to see other vultures diving from a height on to carrion, at a supposed objective to leeward.

It seems more probable that they had left their roosting places the moment the air was soarable in order to go to some food that they had left uneaten the evening before. They were advancing over a front certainly more than a mile wide. Their sudden change from flap-gliding to flex-gliding therefore indicated a widely spread change in the condition of the air.

That slow flex-gliding occurs before fast flex-gliding is illustrated by the following extract from my diary. I have inserted comments in brackets :

October 26th, 1910.—Wind west. Could not be felt till 10.16, when it was just sufficient to move leaves.

9.10.—Widespread circling of cheels began. Nineteen cheels up.

9.14.—Twenty-eight cheels circling in city. Of these three at high level flap-circling. (I have not seen high level flap-circling since last cold weather. During the monsoon season, July to September, as soarability develops, air at a higher level seems frequently to be more soarable than air at a low level.¹)

9.20.—Flex-gliding of cheels beginning.

10.10.—112 cheels up circling over city.

11.12.—Five vultures and one brown vulture seen starting. At first they flap-circled.

10.14.—These vultures were either circling without flapping or flap-gliding up-wind.

10.16.—Six vultures seen slow flex-gliding direct to leeward for about 300 metres distance. They then again circled, but with wings more advanced than had been the case at the commencement of circling.

10.30.—A vulture seen slow flex-gliding up-wind with loss of height. Once it was seen to flap for a few seconds.

10.35.—A vulture slow flex-gliding beam on to wind without loss of height. Wing-tips slightly retired.

10.40.—Seven vultures flap-gliding up-wind at low level.

10.47.—A black vulture circling. Vultures slow flex-gliding up-wind at high level. Other vultures, at lower level, flap-gliding up-wind.

10.50.—Three vultures fast flex-gliding to leeward.

10.53.—Two vultures flex-gliding up-wind with slight relaxation of secondaries. (This adjustment, as will be explained in a later chapter, indicates flex-gliding at medium speed.)

10.58.—A vulture fast flex-gliding up-wind.

10.59.—An eagle fast flex-gliding up-wind.

¹ In the first chapter I adduced reasons for believing that when soarability is fully established it is greater at a height than nearer ground level. But in the year 1909, in the colder months, I frequently noticed that, in fine, nearly calm weather, as soarability was developing, circling cheels on attaining heights of about fifty metres often appeared to reach unsoarable or less soarable air, in that their flight changed to flap-circling while other cheels below them at lower levels remained circling. That is to say, it appeared that in these cases soarability developed first at lower levels and a few minutes later at higher levels. Somewhat analogous phenomena will be mentioned in Chapter XX.

In a later paragraph, when describing certain influences that tend to diminish soarability, I shall bring forward further proofs that flex-gliding demands more air energy than circling.

Before widespread soarability is established it sometimes happens that soarability for cheels occurs for a few minutes over a small area perhaps half a square mile. As this temporary soarability dies away the cheels that had been circling (with gain of height) may glide down steeply and settle. On the other hand, they may glide down to a distance with very gradual loss of height. If they glide down in this way to leeward, it is a sign that soarability will not be established for some time. If they glide down in a windward direction, the loss of height will be more marked, and so doing is a sign that soarability will be developed within a few minutes.

In the case of cheels there is commonly only a slight difference between the dihedrally-up and the dihedrally-down position of the wings. That is to say, the dihedral angle, whether up or down, is usually small. Hence it is somewhat difficult to see, in circling cheels, whether the wings are dihedrally-up or not. In the hot weather cheels usually appear to circle (at least, if circling with effort to gain height) with the wings in the dihedrally-up position. In the cold weather, cheels generally circle with the wings held flat, or sometimes with the wings dihedrally-down. During February, March, and April 1910, I made a number of observations on this point, from which it appeared that in February and March cheels commonly held the wings flat at the time of commencement of circling, and only employed the dihedrally-up position about 10 to 20

minutes later. In April the interval was less, or the dihedrally-up position was used from the commencement of circling. The following example shows differences in the dihedral angle during the development of soarability on a fairly cool day :

16th November, 1910.—Shade temperature at 8.0 a.m. was 61.2° , maximum temperature during the day 82.5° F.

Jharna Nullah. At 9.12.—Wind perceptible from west. Very slight haze. Cheels flap-circling without leeward drift. Taj visible. Cheels had wings flat or dihedrally-down.

9.15.—Three cheels flap-circling with leeward drift.

9.16.—Some cheels near circling and drifting to leeward. Wings occasionally slightly dihedrally-up.

9.18.—Circling cheels gaining height. About 100 cheels now up.

9.20.—Cheels flapping to go up-wind. No leeward drift beyond limits of slaughterhouse yards.

9.22.—A few cheels drifting beyond to leeward. At low levels cheels had wings dihedrally-up. At higher levels wings appeared flat or dihedrally-down.

9.24.—Cheels lift-gliding up-wind with loss of height.

9.25.—Cheels showing more dihedrally-up position of wings and more drift to leeward.

9.29.—Cheels gliding up-wind showed very slight loss of height.

9.34.—Cheels flex-gliding up-wind at medium speed.

9.50.—Wind increasing, and now enough to move leaves.

10.0.—Cheels fast flex-gliding.

The above extract from my diary illustrates the fact that while soarability is developing there is a stage at which there is sufficient air energy for circling but not enough for flex-gliding. During this stage, birds wishing to go up-wind may do so by flap-gliding or by gliding with loss of height. As soarability increases gliding up-wind is no longer accompanied by loss of height. Then at a later stage it is seen to be accompanied by gain of height. As soarability further develops this lift-gliding with gain of height is replaced by flex-gliding in which, as before explained, there is neither loss nor gain of height, but in which the bird travels at higher speed through the air.

In lift-gliding the bird nearly always shows dorso-ventral axis instability, that is a tendency to rotate to and fro round the dorso-ventral axis. Two explanations may be suggested of this instability. Either gliding with wings at full camber and with gain of height as in lift-gliding, is for some unknown reason, necessarily unstable so long as the bird is travelling on a straight course. (This view would explain why travelling on a curved course, as in circling, is so generally employed for gain of height.) Or on the other hand, it might be suggested that lift-gliding is only employed in air in which soarability is not fully developed and in which available air energy is not uniformly distributed, and that this lack of uniformity causes the instability observed. I propose to give a number of extracts from my diary illustrating the phenomena of lift-gliding :

21st January, 1910. At 9.45.—Cheels commenced circling.

9.50.—In lift-gliding I noticed that so long as the bird travelled in a straight line there was a tendency to lose height. But a slight turn to one side or the other was accompanied by a rise.

February 6th, 1910. At 2.9.—A very strong north wind blowing. Much dust in the air, but sun shining. Some cheels flex-gliding at very little height (2ft. or 3ft.) over the tree-tops. (This, as will be explained later, is evidence of " storm soarability.")

2.45.—There was a lull in the wind, but it had not died down completely. A black vulture was seen flex-gliding nearly directly to leeward at a height of less than 50 metres. It passed me (I was on the roof of my house) at about 100 metres distance. While it was passing the wind suddenly freshened. The black vulture at once commenced leelooping. It proceeded thus for about half a mile to leeward. It then began gliding up-wind, nearly in my direction, at a height of less than 100 metres. Its wings were dihedrally-up. During this lift-glide it showed both lateral and dorso-ventral axis instability. As soon as it had advanced a little to windward of my position, it began circling. Instantly the instability vanished. As it circled, it drifted to leeward, showing in each circle a clearly marked gain of height.

The tendency to rotate to and fro round the dorso-ventral axis could clearly be seen to be associated with

gain of height. Whenever the bird, instead of proceeding horizontally, began to glide in an upward direction, at a small angle with the horizon, one wing always appeared to gain more height than the other. Hence the bird always became canted over, and then glided off its course for two or three metres to the right or left. It was as if the bird every now and then was climbing a greasy pole inclined at an angle of about 20° with the horizon, and as if it kept slipping off to one side or the other.

8th February, 1910.—Calm. A cheel was noticed lift-gliding up-wind for a distance of about 200 metres, and gaining height most of the way. It probably gained between 10 and 20 metres. (Time of observation not noted.)

13th February, 1910. At 9.50.—Sunshine began. Cheels seen flex-gliding.

9.56.—Scavengers began circling.

10.0.—Cheel seen lift-gliding up-wind. It was unstable, and showed slight gain of height. It travelled thus for about 200 metres. Then it flex-glided up-wind horizontally.

10.6.—Vultures began circling.

2nd August, 1910. At 4.30.—A vulture lift-gliding had wings even (*i.e.*, not arched), and showed many dip movements.

6th August, 1910. At 6.30.—Wind east, moving branches. Sky clouded.

7.0.—A small patch of sunshine on city. Fifteen cheels up in city. A cheel near me lift-glided for 200 metres, with occasional slight gain of height. Then it leelooped to near the Fort.

14th August, 1910, at Futteypur-Sikri. At 4.0.—Cheels near at low level in flapping flight. But at Sipri (a village a mile away) cheels were circling, and one was seen lift-gliding. It gained perhaps 100 metres in a distance of 500 or 600 metres. While so doing, it showed instability. Then it turned and glided to leeward with loss of height and no sign of instability.

2nd October, 1910, at house. At 4.0.—A black vulture seen at a height of perhaps 300 metres lift-gliding. Its wings were slightly dihedrally-up and slightly advanced. It showed slight instability round longitudinal axis (*i.e.*, lateral instability). After lift-gliding for about 200 metres it began circling. During several circles one small windward dip only was seen, and in two circles I saw retirement of outside wing-tip. Then it again lift-glided up-wind for about 200 metres, and then began flex-gliding with a double dip. In a second or two the double dip was repeated. After the first double dip, the speed was seen to be suddenly and distinctly increased. While lift-gliding, if the bird swerved

to the right, dips or wing depressions of the left wing were seen. The appearance was as if turning to one side or the other was due to some action of the air, and as if the observed dips and depressions were used to correct such turning.

14th November, 1910. At 4.0.—Two black vultures seen on a level with the top of the dome of the Taj, and just beyond it. They were gliding. The one lower in position occasionally flapped. When it reached the level of the higher one, both were seen to be lift-gliding with gain of height. The wings were dihedrally-up and advanced. At the time, in various directions, cheeks were showing more low level flapping than usual, and at greater heights. The wind was west, moving leaves. The black vultures were travelling up-wind, and went out of sight, being eclipsed by a tree in my garden.

6th June, 1911. At 6.45.—South-west wind moving branches. Air clear. No heat eddies. A few thin clouds moving from the north. There had been thunder and rain at 3 a.m., and a strong wind had been blowing since. Cheeks were leelooping and lift-gliding up-wind. But in thus going up-wind, they often showed more loss than gain of height, and there was occasional flapping. At the time of each gain of height, the angle of incidence increased. This increase was often followed by dorso-ventral axis rotation and a swerve off the wind to one side or the other. This is an example of "wind-canting," as will be described at greater length in Chapter XVII.

20th November, 1911.—Shade temperature at 8.0 a.m. was 57.7° F., maximum temperature during the day 65.5° F.

12.14.—After a fine night a white mist covered the ground in the morning. At midday this was gradually rising. The Taj finial was still enveloped in mist. Strong glare. Wind north, moving small branches. A black vulture circling showed slight lateral instability. It was flapping at 12.15. Cheeks showed single wing depressions (the sign of dorso-ventral instability). Slight occasional movements of the tail of a cheek were seen. They were probably rotations round its long axis.

12.22.—Cheeks flap-gliding up-wind showed single wing depressions and tail twisting.

1.15.—Vultures circling were occasionally enveloped in the mist at 250 metres height. Their colour was greenish. Air very cold. Vultures lift-gliding up-wind were steady. Advancing of their wings was clearly shown. Lift-gliding to leeward with occasional flapping also seen, but in this case slight longitudinal axis instability was observed, but no other form of instability.

1.16.—Slight sunshine. Slow flex-gliding of vultures began. Some flap-flex-gliding also observed.

1.17.—Vultures medium speed flex-gliding. Patches of blue sky and glare. Vultures appeared yellowish green when on blue background.

1.26.—A vulture medium speed flex-gliding was occasionally enveloped in the mist at 200 metres height.

21st November, 1911.—Shade temperature at 8 a.m. 57.7° F.; maximum temperature during the day 71.0° F.

3.30.—Vulture lift-gliding nearly directly to leeward. Its wings were advanced. It was steady. I watched it for a long distance. Wind

north-west, moving leaves. Cold. Sunshine. Some isolated cumulus clouds.

23rd May, 1912.—After a dust-storm, in which unusually little instability was observed.

3.57.—Wind less, moving leaves, and occasionally small branches. Cheels settled. Heavy cloud.

4.0.—More wind. Cheels in Fort direction lift-gliding with gain of height. Their flight was steady.

Though the last three observations are the only ones in which I have recognised and recorded stable lift-gliding, they are amply sufficient to prove that this form of flight is not necessarily unstable. Therefore we must conclude that the instability usually seen in lift-gliding occurs because this form of flight is usually employed in air which is not homogeneous in respect of its supporting power. In a later chapter it will be shown that such air is air in which the energy concerned in soarability is not uniformly distributed.

The facts already given may be regarded as presumptive proofs that sun energy is the source of the energy of sun soarability. I have now to describe some observations that, I think, will be regarded as demonstrative proofs of the connection between sun energy and sun soarability. These observations were carried out at Naini Tal during June, 1910.

Naini Tal is situated in the Himalaya Mountains at an elevation of between 6,000ft. and 8,000ft. above sea level. The elevation of Agra is only about 500ft. The air at Naini Tal is consequently more rarefied than that at Agra. It is therefore presumably less buoyant. But in the presence of strong sunshine the air in Naini Tal is at least as favourable for soaring flight as it is in Agra.

The species of birds studied in Naini Tal were the same as those on which most of my observations have been carried out in Agra, but with two additions. The

species of crow present in Naini Tal has the power of soaring at any rate in calm air and in the presence of strong sunshine. The crow found in the plains of India is of a different species and does not soar under any conditions. In Naini Tal I saw a few specimens of the Lammergeyer (*Gypaetus barbatus*), a vulture of 9ft. to 9½ft. span. It has a long tail, and is characterised by slow heavy flight. I have never yet seen in the flight of the Lammergeyer any sign of "relaxation of secondaries," an adjustment that will be described in later chapters as occurring in the flight of other species of vulture.

Gliding flight in mountainous country generally occurs in ascending currents of air. Despite this fact, it will be seen that my observations made in Naini Tal lead to the clearest proofs that in soaring flight energy is taken from the air, and that it is somehow connected with the energy present in the sun's rays.

During the period of my observations (June, 1910) the wind was nearly always so feeble that ascending currents of air produced thereby were not sufficiently strong to support birds in soaring flight unless in the presence of sunshine or at least a strong glare of light. In Naini Tal cheels and vultures could often be seen circling when enveloped in thin cloud. Under heavy cloud, in which the amount of light was diminished, soaring flight did not occur. The observations on which this statement was based were mostly made near a slaughterhouse in Ballia Ravine, just below Naini Tal. I was fortunate in getting permission to use a ledge by the police lines overlooking the precipitous side of the ravine as a post of observation. At this point the Ballia Ravine is about 300ft. deep, and has a width of

1,100ft. Numerous vultures were in the habit of roosting on trees or rocks on the side of the ravine nearest my post of observation. During the daytime wind is nearly always blowing up the ravine from the valley below, sometimes clear and sometimes carrying cloud. Often cloud could be seen in process of formation by condensation from the rising air. When this was the case, the amount of sunshine or glare varied rapidly from minute to minute, causing clearly observable changes in the degree of soarability of the air. For instance:

June 18th, 1910, at Ballia Ravine. At 3.2.—Two cheels were circling in thin cloud. The air current was seen to be slowly rising, though the wind was not sufficient to be felt. As glare decreased from further accumulation of cloud overhead, the cheels were observed to cease circling, and began flap-gliding in circles. No change occurred at the time in the rate of movement of the air.

That is to say, as the glare of light decreased, the air became less suitable for soaring flight. The following is a similar case:

June 26th, 1910, at Ballia Ravine. At 11.45.—Wind very feeble, only occasionally perceptible. Four vultures had been circling enveloped in thin cloud. As the cloud above them got thicker, they ceased circling, and glided down the valley. Two turned back after going a short distance and settled. The other two glided on further till on reaching sunshine they again began circling.

The following extract from my diary is an instance of several successive changes in the degree of soarability occurring coincidently with changes in the amount of glare or sunshine:

Sunday, June 12th, 1910, at Ballia Ravine. At 11.0.—Wind occasionally enough to move leaves. No puffs or eddies. Sunshine near. Two cheels circling. One vulture circling with occasional flaps.

11.15.—Another patch of sunshine. A black vulture, a white scavenger vulture, and some cheels began circling. Shortly afterwards, as cloud rolled up overhead, these birds settled or disappeared.

11.32.—The cloud mass overhead was thinning, so that there was a strong glare. A cheel seen circling in thin cloud. As the cloud lifted a group of twenty-four vultures were seen circling (in sunshine) over a hill two miles distant.

11.40.—Sun shining. The twenty-four vultures glided to the neigh-

bourhood of the police lines. Some settled. A few flex-glided back down the valley and circled in front of an advancing cloud.

12.6.—This cloud was coming near. Two vultures were watched circling in this cloud for about three minutes. They disappeared as the cloud became thicker. This was wet cloud that deposited small drops of water on my clothes.

12.12.—Heavy cloud overhead, so that it was getting comparatively dark. Cheels settling.

12.29.—Though I was still enveloped in cloud, the sun was shining sufficiently to throw faint shadows. Four cheels circling near.

12.30.—Six cheels circling near.

12.32.—Many cheels circling. Vultures starting and gliding down the valley. These vultures, at time of starting, were enveloped in thin cloud.

12.34.—Thick cloud overhead, and noticeably darker. Cheels near had all settled. No cloud below in ravine.

12.35.—More glare. One cheel up circling. Less wind now, not enough to move leaves.

12.36.—Three cheels circling.

12.37.—Many cheels circling.

12.41.—Darker. Thick cloud above and also below me in the valley. Cheels no longer visible, probably settled.

12.44.—Sunshine visible some way down the valley, and cheels there rising and circling.

12.46.—A Lammergeyer seen circling in thin cloud near a patch of sunshine. This was below my level.

12.47.—Sunshine on opposite side of ravine. No cheels up on my side where there was still thin cloud. Four cheels circling down the valley in or near sunshine.

12.50.—Lighter. Cheels circling near, and two vultures gliding.

12.52.—Sunshine. One cheel circling high. Wind imperceptible. Small patches of cloud lying on opposite bank of ravine showed scarcely perceptible movement.

12.55.—Cheels were circling, and white scavengers and vultures were gliding. A Lammergeyer circling, and another flex-gliding.

1.0.—Cloud in ravine disappearing. Sunshine and patches of blue sky. The birds had mostly flex-glided away to a distance, or had circled to a level with the tops of the neighbouring hills.

These observations may be briefly summarised as follows: At the beginning of the period of observation in spite of an ascending current of air, the bottom of the ravine having a rate of ascent of about 1 in 5, the air was not soarable unless there was either sunshine or else a strong glare of light. Towards the end of the observations, as cloud cleared off, the air became sufficiently soarable to permit not only circling but

also flex-gliding, although the ascending wind had so far ceased that its movement was imperceptible.

I made a few observations in Naini Tal on the formation of "heat eddies." As in Agra, these could be seen rising from the tops of houses or from the top of a stone wall in sunshine, and also in thin cloud, provided there was a strong glare of light. If the glare diminished from accumulation of cloud overhead the eddies ceased. Apparently sunlight reflected from a cumulus cloud, or reflected from the snow ranges some 40 or 50 miles away, was not capable of producing heat eddies. Soarability seemed also to need direct action of sun energy. For instance :

June 27th, 1910, at Ballia Ravine. At 3.22.—Slightly more light. A vulture started and, after gliding about 100 metres, returned and settled. Another started and returned after going about 300 metres. There was thick cloud behind me covering the sun. The glare was mostly by reflection from a cumulus cloud down the valley.

But it is difficult to see how heat eddies can be assumed to be source of soarability. They only appear to be formed when sunshine (or glare) strikes solid objects. In the presence of strong glare, when birds are circling in thin cloud, not a trace of any eddy movement or anything resembling heat eddies can be seen anywhere near the birds. The thin cloud is usually not homogeneous, but in more or less discrete masses, so that the movement of every cubic foot of air relatively to neighbouring masses of air can be observed. Sometimes the air in the Naini Tal valley is filled with aerial seeds similar to thistledown but derived from a tree. These float in the air sometimes almost as thickly as snowflakes in a snowstorm. Their movements serve to indicate the direction of the wind as it flows regularly over the level surface of the lake, or as it is

deflected as it meets the sides of the hills. But these aerial seeds show, so far as I have been able to observe, the same irregularity of movement after sunset (when the air is no longer soarable) as they do in the middle of the day (when the air can support soaring flight).

On one occasion I was so fortunate as to observe a cheel circling and gaining height when enveloped in thin cloud and in a descending current of air. The cheel was gliding at first in an ascending current of air over the top of Sher-ka Danda Mountain (height, 7,520ft.) It came down the leeward side of the mountain, past where I was standing, at a point 7,400ft. above sea level, and descended to about 30ft. below me. The air current was just enough to move leaves gently, and was descending probably at an angle of about 15° with the horizon. The cheel then began circling in this descending current and gained height. On the windward side of one circle it made three flaps. Otherwise, without flapping, it regained a position over the top of Sher-ka Danda, and then glided out of sight. The total gain of height in the descending current of air must have been about 150ft. During the greater part of its circling the cheel was enveloped in thin cloud in which as usual not a trace of eddy movement was visible. I recorded in my notes that "at the time the cheel was gaining height, it was in cloud sufficiently thin to let through enough sun energy to make heat eddies, judging from the amount of glare at the time, and from the results of observation of heat eddies that I had made two hours previously."

Had there been a strong wind there might have been a recurved eddy under the lee of the hill of which

the cheel took advantage. This certainly did not exist. There was only a very slight movement of the air, as stated, and had there been any recurved eddy I should have been able to observe it. Further, the suggestion of a recurved eddy does not explain the fact that the cheel was able to circle over the top of the hill. Both in this case and in other cases when birds in Naini Tal were seen circling in thin cloud, the cloud substance was in discrete masses. Hence the movement of every cubic foot of air in relation to neighbouring cubic feet of air could be clearly seen. There was no trace of any visible eddy movements or ascending current that could explain the gain of height.

It will be well to leave for a moment the description of facts to consider the theoretical importance and interest of the above observation. To say that the gain of height might be due to a recurved eddy under the lee of the hill is, I suggest, fair and sound criticism. But as it happens it is a criticism that is easily answered. On the other hand, to say that the gain of height must have been due to some undiscovered upward trend or horizontal pulsation, and that therefore the observation is of no importance, is not sound or valuable criticism. It is merely attempting to make the facts fit a Procrustean bed of preconceived ideas. Preconceived ideas have not hitherto been found to be a safe guide in the study of soaring flight. Preconceived ideas taught that soaring flight must be due to the bird having skill in finding and using ascending currents. Never was a theory more hopelessly at variance with the facts of the case. How, in the absence of evidence, can we be sure that the preconceived idea that sum-

marily disposes of gain of height in a descending current is worthy of more respect? Whatever future research may show, the facts as they at present stand are very difficult to harmonise with the idea that soaring flight is due to pre-existing streaming movements of the air. We know that the sun's rays are the source of the energy involved. We do not as yet know the nature of the process by which this energy becomes available for doing mechanical work. The subject is one on which the evidence should consist of facts, and not of preconceived ideas. The facts I have brought forward and other facts that I am about to bring forward seem to contradict all recognised theories of soaring flight. It is more important to accumulate further evidence than to attempt a premature explanation.¹

I have already stated that when in the evening soarability decreases cheels and scavenger vultures are in the habit of collecting at the Agra Fort, and gliding in the ascending current of air over the windward battlements. With a certain strength of wind these birds occasionally glide along the battlements for long distances, keeping uniformly at a height of about 4ft. or 5ft. above the parapet. The distance along the battlements from a bastion near to the Delhi Gate to the next is 108 metres. On April 15th and 16th, 1910,

¹ This book is written, not with the object of proving or disproving any particular theory, but rather with the object of stating the facts of the case. Hence the student who wishes to find arguments for or against any particular view may have to cull them from different chapters. For instance, a further proof that birds avoid ascending currents in a soarable wind will be found in Chapter XIV., where facts are adduced that show that birds have a good reason for avoiding such currents. (See also entry "Soaring Flight" in index.) The case of the cheel gliding upwards in a descending current cannot be disposed of on the ground that it is, as must be admitted, an isolated observation. Though in a sense less striking, the numerous observations of cheels circling in thin cloud in which air movement was nearly or quite invisible are in reality even more irreconcilable with existing theories. It is impossible to imagine a more equable and even movement than that of wisps of cloud in the hills when wind is nearly absent. Observation of a cloud mass from a distance is not a case in point. A cloud mass may be condensing at one end, and dissolving at the other, thus producing an appearance of rest in the presence of a light wind. The cases I am referring to are cases in which I was sometimes enveloped in the cloud, and in which the cheels were circling and gaining height often within a few feet of where I was standing. But, as already stated, this only occurred in a strong glare of light. If thicker cloud rolled up overhead, the circling ceased. No change could be seen in the character of the movement of the air.

I noticed that cheels glided this distance in 13, 14, and 14 seconds ; this corresponds to a speed of 7.7 metres per second. Scavengers did the same distance in $11\frac{1}{2}$, $11\frac{1}{2}$, 12, and 12 seconds, equal to a speed of 9 metres per second.

On May 11th, 1910, when seated on the Delhi Gate at a point slightly above the level of the battlements, I made the following simple observation, which led to results of some importance :

5.30.—Cheels noticed that were gliding beam on to the wind, parallel to the battlements, and at a height of 3ft. or 4ft. above them. The secondary quills of the leeward wing appeared relaxed ; the hinder ends of these feathers, that is to say, were higher than the ends of the feathers of the windward wing. The difference in level was probably 1 centimetre, perhaps as much as 2 centimetres. The birds were gliding on a level keel.

This observation led me to notice the position of the secondaries under different conditions. On the following day I was watching cheels "wind-facing" over the battlements in a light wind. Suddenly the wind increased in strength. Immediately the cheels relaxed their secondaries and increased the flexing of their wings, that is to say, instead of ease-gliding, they were flex-gliding. Their speed had increased *pari passu* with the increase of speed of the wind, so that they retained their position over the battlements. Hence the peculiar appearance presented by the wings of cheels in flex-gliding is due to the fact that, concomitantly with the decrease in span, there is a relaxation of the secondaries, which as I shall show later, is equivalent to a decrease in camber in the case of slow flex-gliding. In the case of fast flex-gliding the camber of the wing is not only decreased but actually abolished. When a cheel is gliding with wings extended the posterior margin of the wing (formed by the free ends of the secondaries) forms a straight line. When flex-gliding, the

posterior margin is no longer a straight line but forms a curved line with the convexity upwards. In cheels when flex-gliding the relaxation affects mostly the more centrally placed of the secondaries. In vultures, when flex-gliding all secondaries appear relaxed to the same extent.

The evidence in my possession goes to show that a particular amount of flexing of the wing and relaxing of the secondaries corresponds to a particular speed. For instance:

August 28th, 1910. At 11.40.—A vulture slow flex-gliding with wings slightly flexed was seen to make a double dip. During the up-stroke of this double dip, the wings were seen to acquire extra flexing. This extra flexing was retained, and was followed by an immediate increase of speed.

If, as frequently happens, flexing is increased without a double-dip movement, then the consequent increase of speed is gradual instead of almost instantaneous, as in the above case. That the increase of flexing in such cases is accompanied by increase of relaxation of the secondaries will be proved on a later occasion.

The above facts give a further insight into the nature of flex-gliding. It is now necessary to consider facts that prove that more energy is required for flex-gliding than for circling.

In Agra, I have observed several instances in which the development of cloud shadow, caused by a thin layer of cloud, may cause flex-gliding to cease while permitting birds to continue circling. Though I have only recorded a few such cases, it is probably not an infrequent occurrence. An unaccustomed observer, on seeing circling with a gain of height going on in the absence of sunshine, might infer that cloud shadow has no effect on soaring. I was for some time in this position, and it was only after more lengthy experience that I realised the different effects of thin cloud shadow on circling and flex-gliding.

Examples of decrease of soarability of this nature are as follow :

March 9th, 1910. At 12.10.—Wind north. Leaves still. A thin layer of cloud. No birds up except cheels. These were either circling or flex-gliding. No ease-gliding seen except apparently on windward side of Fort.

12.30.—Still cloudy. Scavenger vulture seen circling, with occasional flapping.

12.34.—Sunshine.

12.35.—Cheels seen flex-gliding, but with loss of height. No flex-gliding had been seen previously.

March 12th, 1910. At 3.0.—Thin cloud, but sun making faint shadows. Heat eddies strong. Vultures were flex-gliding and circling.

4.0 to 5.0.—Stronger cloud shadow and heat eddies ceased. Vultures, if at low level, were flap-gliding. If at higher level they were circling.

July 22nd. At 8.15.—Cheels near me had been flex-gliding. Shade came over. Then the cheels that were flex-gliding tightened their secondaries, but for a little time continued gliding up-wind. Then they ceased such gliding, and confined their movements to circling, or if at low level to flap-circling. A little later flex-gliding at high level was seen.

In this last case, so long as sufficient air energy was available, the cheels were flex-gliding at high speed with secondaries relaxed and with wings strongly flexed. When, owing to the development of cloud shadow, less energy was available, the cheels at first decreased the flexing of their wings and the relaxation of their secondaries, and flex-glided at lower speed. Then, as the available energy continued to diminish, they extended their wings still further, and with a further decrease of speed began circling.

It might be thought that this last observation proves that the bird has some mysterious power of knowing how much air energy is available, and that in consequence it can trim its wings accordingly. Though I have no wish to allow abstract speculation to obtrude on this record of observations, I may briefly state my opinion that the facts now described prove nothing of the kind. For, as will be apparent in later chapters,

existing evidence goes to show that the centre of effort of the wings bears a different relation to the centre of gravity, according as the bird is or is not taking energy from the air. Thus the only assumption necessary is that the bird is aware when it is losing its balance, and that it can recover or preserve its balance by appropriate adjustments. Some of these adjustments have been already described, others will be described in later chapters.

The following is a case of flex-gliding observed in Naini Tal :

June 21st, 1910. At 12.57.—A vulture seen flex-gliding up-wind at 20 metres per second and at a height of 800 metres above my point of observation. This was on Sher-ka Danda, at a point 7,400 ft. above sea level. After passing over me it glided in and out of thin cloud. Several clouds were near, but the sun was shining. Wind light, occasionally moving leaves.

In Naini Tal, whenever the air has full soarability owing to the presence of bright sunshine, vultures could be seen circling up to a height of several hundred metres above the mountains. When they had thus reached a sufficient height they would flex-glide away, and could sometimes be seen thus gliding for several miles before they went out of sight.

On two occasions I have seen vultures flex-gliding at a height of about 1,000 metres above my laboratory in Naini Tal. This laboratory is 7,400ft. above sea level. Most of my measurements of speed of flex-gliding in Naini Tal have given speeds of from 20 to 24 metres per second. That is to say, in spite of the rarefaction of the air at this height in the Himalaya Mountains, as much air energy is available for soaring flight as in Agra, where the ground is about 500ft. above sea level.

CHAPTER VI.

A FURTHER DESCRIPTION OF STEERING MOVEMENTS.

It will be advisable to commence this chapter with a point of nomenclature. The accompanying figures represent outlines of the green parrot (*Palæornis torquatus*), a bird common in Agra, and one that has the power of very rapid flight.

Fig. 21 shows the outline of the wings in what I propose to call the “advanced” position. This disposition, as will be described in a later chapter, occurs when the bird is about to perch. The outline of a dove under similar conditions would be different only in the fact that the alula would be seen

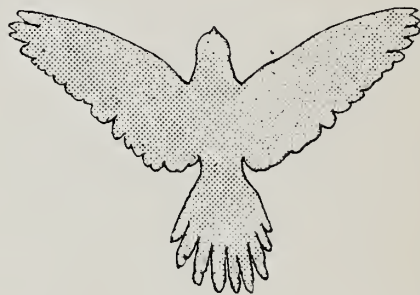


FIG. 21.

Outline of a parrot with wings advanced.

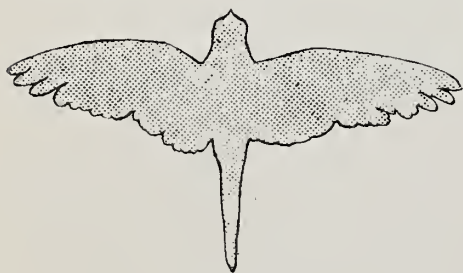


FIG. 22.

Outline of a parrot with wings straight.

to be extended.

In fig. 22 a parrot is represented with the wings in the position that I propose to call “straight.” The wings leave the body at a right angle. Their centre of effort is on the same level as the

centre of gravity. This position is seen in rapid horizontal flapping flight. The wings are shown slightly flexed, as is usual in flapping flight.

In fig. 23 I have shown the wings in the “retired” position. This is the position assumed by the wings

of a parrot when it is in flapping flight in a downward direction. The wings are also retired when the parrot is gliding downwards without flapping. In this case, besides being retired, the wings are held in the dihedrally-down position. When thus gliding with the wings dihedrally-down, the centre of effort of the wings is slightly above the position of the centre of gravity. The centre of effort of the wings is only below the centre of gravity during the downstroke of a double-dip movement, that is to say, when the bird is rotating round the transverse axis.

In an earlier chapter I described two kinds of movements that are used by birds for steering in the horizontal plane. The first is the "dip," which has been shown to be due to a rotation of the wing-tip. The second movement is the "depression." The question arises whether the depression observed is an actual depression of the whole wing caused by direct muscular action, or whether it is due to a rotation of the wing and the resulting depressing effect of the air striking its upper surface.

That the depression is a movement of the same nature as the dip, namely a rotation, is indicated by the following facts: Firstly in the case of cheels, the two modes of steering are usually combined. If a cheel is gliding with wings extended steering may occur by a wing depression or by a compression combined with a dip. I have no clear recollection of seeing a dip movement in a cheel without there being

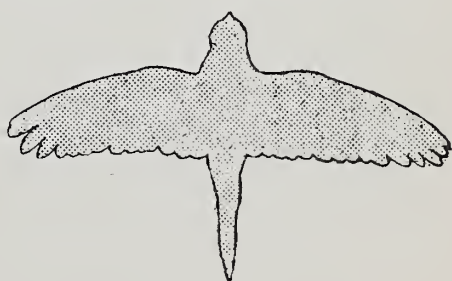


FIG. 23.

Outline of a parrot with wings retired.

at the same time some appearance of depression of the whole wing.

Secondly, where, as in the case of vultures, the two kinds of steering movements are usually distinct, one or the other may occur apparently under the same conditions. For instance :

June 12th, 1910, at Ballia Ravine. At 12.6.—A vulture started from a tree near me and glided in a nearly straight line for about two miles. During the first part of this glide, two steering movements were seen, one a dip and the other a depression of the whole wing. The latter produced the stronger change of course.

Thirdly, in the case of the double-dip movement, it is often difficult to see how far it is due to a movement of the wing-tip and how far to a depression of the whole wing. Only after my arrival in Naini Tal did I have opportunities of making observations with definite results, as shown by the following evidence :

June 19th, 1910, at Ballia Ravine. At 12.30.—Sun shining. A brown vulture while ease-gliding down the valley showed a momentary depression of both wing-tips, presumably for the purpose of increasing speed. A lammergeyer seen making a double dip. This was clearly seen to be due to a depression of the whole wing, and not merely of the wing-tips.

June 21st, 1910, at Ballia Ravine. At 3.23.—A lammergeyer seen to make a double dip twice over at short intervals. These dips appeared clearly as a bending down of the wing at the carpal joint. At the time the vulture was gliding downwards at speed. The alulæ were not extended. Then it again made a double dip, which was as clearly seen to be not at the carpal joint but at the shoulder joint. A minute later it made another double dip, which appeared to affect both shoulder and carpal joints.

Hence double dips may be seen either as a dip of the wing-tips caused by rotation of the digital quills, or as a dip at the carpal joint certainly due to rotation of the outer part of the wing, or as a dip of the whole wing in which rotation may also play a part.

I also attempted to settle the matter by direct observation. I will give my records in full, as it is interesting to see how much practice was required before I could make this somewhat difficult observation.

My notes include various surmises of no value except as showing that I was uninfluenced by any particular preconceived idea while carrying out the observations. My diary extracts are as follows :

July 18th, 1910, at Agra. At 6.40 a.m.—Four cheels up near. They were circling at low level with occasional flaps. Steering was by whole wing depression. During the depression the wing, when seen from behind, looked thicker than it does in gliding flight.

July 24th, 1910. At 9.47 a.m.—A cheel gliding up-wind. It gave the impression that on dipping the whole wing the secondaries—that is to say, the hinder or free ends of the secondaries—went up. Also in several other cases the depression seemed to be accompanied by an appearance of thickening. This suggests that the depression is caused by a rotation of the wing.

July 27th, 1910. At 5.20 p.m.—A cheel during a wing depression showed relaxation of secondaries. Perhaps this was due to a twisting of the wing.

August 5th, 1910. At 7.4 a.m.—A cheel wind-facing made a whole wing depression. This gave the same impression as the movement of one of the wings in a double dip.

At 7.24.—A cheel making a whole wing depression showed slight movement upwards of secondaries, while at the same time the wing-tip went downwards as in a dip movement. Does a whole wing depression mean a slight arching of the wing, which would involve less efficiency, and therefore a steering effect?

August 14th, 1910, at Futteypur-Sikri. At 8.45 a.m.—An eagle seen gliding up-wind. Twice a whole wing depression was seen clearly to be accompanied by a rising of the free or hinder ends of the secondaries. Because the wing depression is not accompanied by any increase of flexing, therefore the wing depression must be due to a twisting of the whole wing. (Facts to be described in a later chapter will make clear the meaning of this argument.)

August 16th. At 7 a.m.—A cheel while gliding showed an elevation of the free ends of the secondaries—that is to say, rotation of the wing, which was seen to be followed by depression. I was very astonished at being able to see this.

This last observation was quite unexpected. Though I have no doubt that it represents accurately what actually happens in a wing depression, I am inclined to think that it was of the nature of an accident that the rotation of the wing was presented to my consciousness as a phenomenon preceding the depression. Since making this observation I have frequently been able to see that in a wing depression the front edge of the wing

is depressed and the hind edge is slightly elevated. There can, therefore, be no doubt that the movement consists in a rotation of the wing, and that the depression ensues when the wing is no longer supported as before by the air pressure from below.

The above observations, therefore, point to the conclusion that birds may steer in the horizontal plane, either by rotation of the wing-tip or the whole wing.

It is necessary to consider possible criticisms of this conclusion.

1. When describing the flapping and other movements connected with perching I shall show that the wing when in use can be rotated through an angle of nearly 90° . There is therefore independent evidence of wing rotation.

2. That the movement observed cannot be due to relaxation of the secondaries of the depressed wing, that is to say to a diminution of camber, will be shown when I come to describe the mechanism for altering camber in the following chapter.

3. That the rotation of the wing, or of the wing-tip, for steering in the horizontal plane is not accompanied by a rotation of the other wing, or of the other wing-tip, in the opposite direction will shortly be proved.

4. In a later chapter I shall have to describe cases in which a slight relaxation of the secondaries of the outside wing plays some part in steering.

5. In Chapter VIII. I shall describe my observations on the conditions under which tail-less cheels are unstable. It will be seen that the facts observed lead to the conclusion that movements of the tail do not produce steering effects.

6. Cheels may on rare occasions show sudden rotation round the dorso-ventral axis through as much

as 90° , or even a larger angle. I shall describe these rotations in Chapter X., and shall show that they have nothing in common with ordinary steering movements.

In view of the knowledge gained of directive movements, a further description of circling may be attempted.

The first steering movement in circling that I discovered is one that I propose to term the "windward dip."

If a circling bird is carefully watched at the end of the windward gain of height, a slight downward dip of the wing-tip of the wing that is nearest the centre of the circle may be observed. This windward dip may be seen occasionally in all species of soaring birds that have come under my observation, including vultures, cranes, and adjutants.

While watching a cheel circling a few feet over the roof of my house where I was sitting at the time, I noticed the windward dip in two or three circles. Then in the following circles, at the point in the track where one might expect to see the dip, a sudden wing depression occurred. Thus the dip was replaced by the other kind of steering movement that has been described. This steering movement was seen to be followed by a slight rotation of the bird, that is to say, by a slight change of course.

In cases in which a leeward gain of height occurs this gain may be similarly followed by a "leeward dip."

Both with the white scavenger vulture and the black vulture I have on rare occasions noticed that at the time of the windward dip the whole of the inside wing was momentarily depressed, and that the outside wing was also depressed, but to a lesser degree. In view of the description of the effect of the dihedrally-down position given in Chapter IV., it appears probable that these adjustments have the object of increasing speed.

In lee-looping the windward dip may often be seen. At the leeward end of the glide a dip of the inside wing may occur, evidently with the object of turning the bird round to face the wind. After the windward gain of height the windward dip may be seen. Then, when in consequence the bird turns round (to a direction facing away from the wind) to commence the next leeward glide, I have in the case of the cheel and the white scavenger, frequently noticed a depression of both wings to a slightly marked dihedrally-down position. This adjustment only lasts for a second or two, and its function appears to be to produce or initiate the increased speed of the leeward glide.

Several months' study was requisite to discover the above facts of directive movements in circling. After several more months' study I discovered smaller movements of the tip of the outside wing that occasionally occur. These movements appear to be of a somewhat complicated nature, and I propose discussing them on a future occasion.

On rare occasions, and if one is favourably situated for observation, other dip movements of the inside wing-tip may be seen. These are of lesser amplitude than the dip movements already described.

The extraordinary fact about these different movements is that they do not always occur. Sometimes I have observed carefully perhaps as many as a hundred birds without once seeing a windward dip. Sometimes at Jharna Nullah, out of thousands of birds circling together, none show any such movement. Presently a cluster of birds may be seen to detach themselves from the rest, and commence drifting to leeward. Every bird in this cluster that can be observed will be found to show

strongly marked windward dips. Another cluster of birds drifting to leeward may show scarcely any such movements.

The bird is always canted over towards the centre of the circle. If the air is fully soarable the wings of the vulture when circling are in the dihedrally-up position. On the down-wind side, especially at the commencement of the down-wind side of the circle, the dihedrally-up angle is less, or the wings may for a short period be held nearly flat. When circling in less soarable air the dihedrally-up angle also is less, and in this case, along the down-wind side of the track the wings may be held flat.

But whether the wings are flat or dihedrally-up, their centre of effort is always above the level of the centre of gravity. It might be suggested that the canted position in circling is connected with this fact, in that it might be due to an effect of centrifugal force. But this supposition is clearly negatived by the fact that the amount of canting is greatest on the windward side of the track, where speed is least. Canting is least on the down-wind side, where the speed is highest. On the windward side of the track the bird may be canted up to such an extent that the plane of its wings (supposing they were flat) may make an angle of between 30° and 60° with the horizon.

The amount of canting varies at different times without any very obvious cause. I have formed the impression that in ease-circling there is less canting than there usually is in circling with effort to gain height.

We may hope to understand these facts when we have more knowledge of the method by which the bird obtains energy from the air.

Warping of the wings of an aeroplane to equal amounts in opposite directions may conveniently be referred to as "Wright's method."

There is a certain resemblance between the warping of the wing of an aeroplane and the rotation of the wing-tip found in birds. One would therefore expect that birds use Wright's method for preserving lateral stability, or as it may otherwise be expressed, for producing or checking rotation round the longitudinal axis.

But I am acquainted with no evidence that Wright's method is used by birds. In other words, during a dip movement of one wing, there is no evidence of any upward rotation of the front edge of the wing-tip of the other wing. At the time that I made the following observation I thought that I had found an instance of the use of Wright's method :

June 30th, 1910, at Ballia Ravine. At 2.30.—High level clouds only. A few vultures perched, and one in sight in the air. Slight sunshine. A lammergeyer seen circling near. The first quill feather of the outside wing was turned up while the bird faced the wind, but not when the bird was travelling with the wind. The gradual return of the end of the feather to the horizontal position was clearly seen as the bird turned in each of several successive circles. The wind at the time was nearly imperceptible, but occasionally moving leaves slightly.

Further experience has shown that the above observation cannot be regarded as an instance of the use of Wright's method. The return of the first quill feather to the horizontal position, mentioned in the above extract, was not its return to the normal position. On the other hand, as shown in fig. 24, the tips of the digital quills when circling are normally turned upwards. The first quill assuming the horizontal position in the above instance was of the nature of a half-dip movement, as will be further described and explained in a later chapter. The range of movement observed

in this instance of the first quill feather was probably less than 2in. The bird was probably of 9ft. span or more.

That canting in soarable air is not merely a consequence of travelling on a curved course with the centre of gravity below the centre of effort of the wings is shown firstly by the facts of canted flex-gliding. In this form of flight, as elsewhere described, the bird is canted though travelling in a straight line. Secondly a similar conclusion can be drawn from the phenomena shown in circling where the amount of canting is inversely proportional to the speed.



FIG. 24.
Transverse section of a vulture when
circling in fully soarable air.

- CG. Position of centre of gravity.
- C. Carpal joint.
- M. Metacarpal joint.
- Al. Position of alula, shown by dotted line.
- I., II., III., IV. Tips of digital quills pressed upwards by pressure of the air.
- V. Position of metacarpal quill tips.

Parrots and pigeons in fast flapping flight on a curved course are always canted. I have seen an adjutant bird become canted while flapping and then cease flapping and begin circling. This observation makes it improbable that the canting was produced by any movement of rotation either of the wing or of the wing-tips, as will be apparent when I come to describe the facts of flapping flight.

In a later chapter, when describing "dropping turns," I shall mention cases in which canting is produced by momentary increase of flexing of one wing. This acts simply by decreasing the supporting area of the wing, which therefore drops a short distance through the air, producing the canted position. In Chapter VIII. I shall describe cases in which canting is produced or removed by "arching" of one wing.

We have now described the methods used for steering to right or left in the horizontal plane, that is to say, the adjustments for producing or preventing movements round the dorso-ventral axis. We have also described the method employed for changing course upwards or downwards, that is to say, the adjustment for producing or preventing movements round the transverse axis. This latter adjustment was only discovered by studying cases of movement round this axis of extreme degree. We may expect that the adjustment used for producing turns round the longitudinal axis will similarly be discovered by study of cases of movement round this axis of extreme degree. Of such cases the extreme degree of canting sometimes observed in circling is not suitable for observation. The bird acquires this canted position gradually. It also returns to a less canted position quite gradually. Therefore, if the canting is due to an adjustment, which is by no means certain, this adjustment must come into operation gradually and hence be difficult to recognise. Other cases of sudden oscillation to and fro round the longitudinal axis will be met with when describing lateral instability and will be found to be due to atmospheric irregularity. But another case of oscillation round this axis is known to me which is suitable for the observation in question. Cheels when swooping steeply downwards sometimes show oscillations of large extent round the longitudinal axis. A study of the conditions under which these oscillations occur will be found to give some clue to the nature of the adjustment used for maintaining lateral stability. Unfortunately this case must be described in a later chapter, as the facts will not be intelligible until I have described flapping flight, etc.

CHAPTER VII.

METACARPAL DESCENT.

That a bird should flex its wings and glide downwards with speed increasing under the influence of gravity, is what one might expect to happen, and I have already quoted examples of such an occurrence.

That a bird flexing its wings to a lesser degree should glide downwards at an angle of about 10° or 15° with the horizon, with speed continually decreasing, in spite of the action of gravity, is not what one would expect to happen. I therefore thought that it would be worth while to devote attention to this phenomenon, for which I had exceptionally good opportunities during my stay in Naini Tal. It will be seen that the attempt to explain this decrease of speed will involve an advance in our knowledge of gliding flight.

Vultures returning to roost on the trees in Ballia Ravine could be seen circling near the top of the end of Sher-ka Danda Mountain and then gradually circling downwards in a large spiral. When they commenced this descent they placed their wings in a slightly flexed position and glided downwards in circles of decreasing diameter and at a diminishing speed. The vertical distance through which they circled before reaching their roosting place was between 350 and 400 metres. They usually took from 60 to 80 seconds to make this descent.

On a day on which vultures had been flex-gliding at 18 to 24 metres per second, I noticed one circling downwards at 12 metres per second. When it had reached a lower level I estimated its speed again and

found it to be 8 metres per second (June 21st, 1910). Another vulture when circling down but still near the top of Sher-ka Danda, was found to be travelling at 12 metres per second. On different occasions I found the following values for the speeds of vultures circling downwards near the end of their descent: 9, 6, 6, 3, and 3 metres per second.

Usually, but not always, when circling downwards the feet were hanging down. As the bird neared the perch, first its legs and then the legs and body were allowed to hang down below the level of the wings. The alulæ were either not extended at all, or if they were extended this only happened a short time before perching. In the case of a lammergeyer (on June 21st, 1910) I have on one occasion seen both alulæ extended and rotated upwards during the whole of several successive circles during descent. Occasionally, besides the feet, the legs were also partly hung down while the vulture was at some distance from the perch.

A vulture descending with legs hanging down was once seen to be struck by a puff of wind. It responded by momentarily increasing the flexure of both wings.

Of the different adjustments that may be supposed to act as brakes in decreasing speed it will be obvious from the above brief description that extension of the alulæ or hanging down of the legs or feet must be of subordinate importance and need not here be further considered. A peculiar kind of flapping that occurs just before perching will be described in a later chapter under the name of "stop-flapping." It will be shown that this acts as a brake.

My observations soon showed me that during descent with loss of speed the camber was maintained

at its maximum instead of being decreased, as it is in ordinary flex-gliding flight. I propose first to attempt to prove the correctness of this observation, and then after explaining the mechanism for altering camber, to bring forward reasons for believing that in descent with loss of speed there is an adjustment that tends to put out of action the lifting and tractive power of the cambered wing. There can be little doubt that in this adjustment it is the brake that is of importance in decreasing speed.

First, by way of proving the correctness of my observation of maintenance of camber in descent, I may refer to my description of the descent of vultures

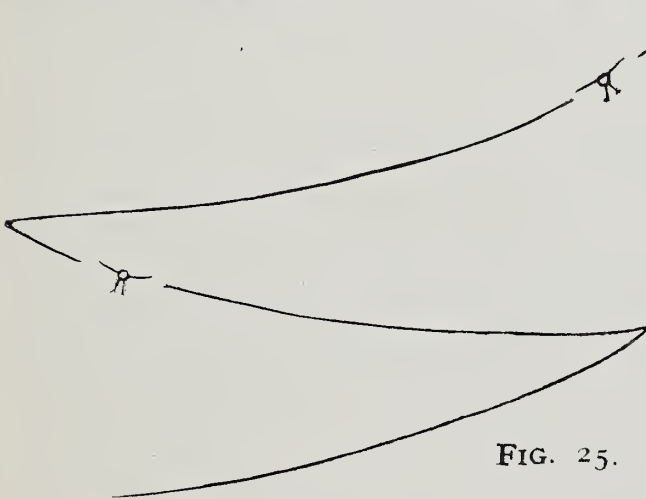


FIG. 25.

Track of a vulture when "parachuting," seen from in front. At each angle of the zigzag the bird makes a dropping turn—that is to say, having been canted in one direction, the upper wing descends, so that it becomes canted in the opposite direction.

at Futteypur-Sikri (Chapter IV.) I stated that towards the end of their descent the vultures exhibited a swaying from side to side, to which I gave the name of "parachuting." The track of a bird when parachuting is shown, as seen from in front, in the accompanying fig. 25. At each angle of the zigzag the bird makes a "dropping turn." Somewhat suddenly its cant in one direction is changed to a cant in the opposite direction. While making this change the bird continues to face almost or quite in the same direction. There may in some cases however be a slight rotation round the dorso-ventral axis during the turn.

As during these dropping turns the centre of gravity is far below the centre of effort of the wings, I was under the impression that the bird was oscillating from side to side like a pendulum, and that any tendency to oscillate in a fore and aft direction was quenched in some way that tended to cause the bird to lose height and speed. My observations at Ballia Ravine, however, showed me that this movement was not automatic (in the sense of being due to a pendulum-like oscillation) but that it was voluntary, and due to an adjustment that I was fortunately able to discover. After watching a number of vultures descending one after the other, and each making a dropping turn at about the same position, at first I saw that there was some displacement or movement of the secondaries of the wing that became lower at the moment of the dropping turn. Then, as I became more practised in making the observation, I formed the impression that at the moment of turn there was a temporary increase of flexing of the inside wing. Lastly, I was able to see with certainty that this sudden and temporary extra flexing occurred and that it was accompanied by a momentary relaxation of the secondaries. Thus a dropping turn is an example of a bird becoming canted by decrease in supporting area of the wing that thereupon becomes lower in position.

The import of this observation of the slackening of the secondaries during the dropping turn is that it proves the correctness of my observation that the secondaries were not relaxed while a dropping turn was not taking place. That is to say, during descent with loss of speed secondaries were kept tight.

Owing to the fact that at Ballia Ravine I was on the same level as the birds under observation, I was

able on a few other occasions to observe relaxation of the secondaries. The details of these very difficult observations are as follow :

June 17th, 1910. At 2.34.—A vulture circling, in air blowing up the valley, was seen to relax the secondaries of the outside wing on the leeward side of the circle.

9.43.—A vulture, to avoid another, was seen to dive by double dip and momentary relation of the secondaries.

June 21st, 1910. At 2.35.—A vulture turning showed slight relaxation of secondaries of outside wing.

June 25th, 1910. At 12.35.—A vulture turning in thin cloud near seen to slacken secondaries of outside wing.

June 26th, 1910. At 11.36.—Two vultures ease-gliding, and then commencing to descend. I formed the impression that the tightening of the inside wing secondaries occurred while turning. After the turn (which was a turn in the horizontal plane), the secondaries of both wings were tightened—that is to say, the wings were adjusted for descent by increase of camber to maximum.

Two vultures descending showed a double dip, accompanied by increased flexing of wings. In each case, at the time of increased flexing, a relaxation of secondaries was seen.

What I have described in the above diary extracts as “relaxation of secondaries” was a moving upwards of the posterior margin of the inner or cambered part of the wing. The movement cannot in any case, except the last mentioned, have been as much as 1 in. in birds of 7ft. or 8ft. span. These observations therefore were difficult to make, and at the time entirely unexpected. It will be seen that they refer to two kinds of relaxation : one, quite momentary, coincident with a momentary but visible increase of flexing ; the other lasting perhaps for several seconds, in which no increase of flexing was observed. That in this latter case a slight increase of flexing must have occurred will be shown in the sequel. It will also be shown that in each case the relaxation of the secondaries was equivalent in a decrease of camber, and was a disposition for increase of speed.

We have now to consider more closely the nature of the wing flexing shown by the descending vulture. Whilst taking their time of descent with a stop-watch I soon learnt to distinguish at a glance between a descending and a flex-gliding bird. There was some difference in the appearance of the flexed wing in the two cases, but not a difference that I could grasp sufficiently to express in words.

It will facilitate description if I mention two theories that I formed to account for the appearance of the descending bird :

Firstly it occurred to me that possibly in fast flex-gliding the flexure is more at the elbow joint, while in descending possibly the flexure was more at the carpal joint. It was conceivable that the ligaments of the wing should be so arranged that one kind of flexing would affect camber and the other have no effect on camber.

Secondly the idea occurred to me that the maintenance of camber in the descending vulture might be due to direct muscular action. I had some recollection of a muscle that I had found in the wing of a vulture that appeared to be capable of producing this adjustment.

After my return to Agra I put these theories to the test by dissection of an adjutant bird of 9ft. span, and later on of a vulture of 7ft. span.

Firstly, with regard to the idea that change of camber may be due to muscular action, as I expected I found a muscle that originates on the lower end of the humerus. Its tendon does not run straight, but follows a somewhat curved course with its convexity backwards. This tendon is inserted into the lower end of the ulna. As shown in fig. 26, extensions from this

tendon go to the membrane that binds together the bases of the outer secondary quills. The result of this arrangement is that on pulling the muscle its main tendon becomes straightened. There is therefore a pull on the extensions. The outer secondaries are thereby drawn downwards and also inwards towards the body of the bird. This displacement of the secondaries is in effect an increase of camber, but the action is slight. It cannot therefore be denied that the action of this muscle may have to do with the maintenance of camber. But its possible action does

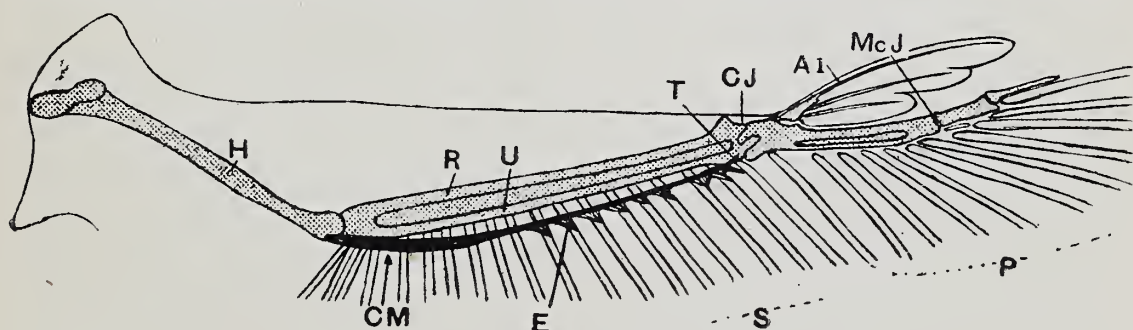


FIG. 26.

Dissection of wing of an adjutant showing "camber muscle."

- | | |
|------------------------------------|----------------------------------|
| H. Humerus. | S. Bases of secondary quills. |
| R. Radius. | CM. Camber muscle. |
| U. Ulna. | T. Insertion of tendon of camber |
| CJ. Carpal joint. | muscle into lower end of |
| Al. Alula. | ulna. Tendinous exten- |
| McJ. Metacarpal joint. | sions (E) of this tendon are |
| P. Basis of primary quills (eleven | inserted into the outer eight |
| in number in this specimen | or nine secondary quills. |
| instead of the more usual | |
| number, ten). | |

not seem proportionate to the effect actually observed, and it appears more probable that the chief function of this muscle is of a less important nature, such as arranging the feathers on furling the wing.

Secondly, I investigated the relation between change of camber and change of flexing. On holding the wing loose in the hand and extending and flexing the different joints no certain effect on camber can

be observed. But a different result accrues when the wing is held firmly by clamps attached to the radius and ulna. It is advisable to clamp the wing horizontally and upside down, so that the weight of the quill feathers to some extent imitates the effect on them of the pressure of the air when in use. On fully extending a wing so clamped the camber is seen to be at its maximum. Flexing at the elbow joint is found to have only a slight effect in decreasing the camber. On flexing at the carpal joint the camber decreases greatly, the decrease being within limits in proportion to the amount of flexing. In certain cases in flex-gliding the alula becomes visible in such a way as to prove definitely that the flexing is carpal. That is to say in flex-gliding the flexing of the wings is an adjustment that, so to speak, automatically diminishes camber. The more the wings are flexed the greater is the decrease of camber and the greater is the speed. I shall have to describe these changes in greater detail when I bring forward evidence in a later chapter as to the direction from which the energy of soarability is operative.

On the other hand, I discovered that if flexing is carried out at the metacarpal joint no effect on camber is produced. This metacarpal flexing retires the wing-tip, as seen in the descending bird, but leaves the wings at their maximum camber.

There can, I think, be no doubt that the peculiar appearance of the descending bird is due to the flexing being metacarpal and not carpal. I propose the term "metacarpal descent" for the mode of descent now under consideration.¹

¹ Supposing a bird is gliding horizontally with wings extended. Supposing a fore and aft section is taken through the wing, such a section is a section at right angles to, or transverse to, the long axis of the wing. The sections shown in figs. 27, 28, and 29 are of this nature.

In fig. 27 I show two sections of the wing of the adjutant bird. A represents the section with the wing fully extended, and B the section taken with the secondaries relaxed by flexing at the carpal joint.

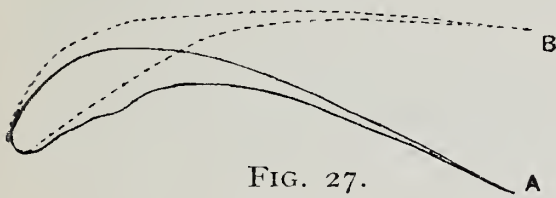


FIG. 27.

For taking these sections the wing was held upside down. The feathers were consequently merely extended by their own weight.

Sections of wing of an adjutant at elbow-joint: At A with wing extended, at B with wing flexed. For taking these sections the wing was held upside down. The quill feathers assumed the position given to them by their own weight only.

But in actual flight the feathers must be pressed by a force much greater than their own weight. I attempted to imitate this force by attaching a weight of 10 grammes to each secondary while the wing was held upside down as before. This weight was chosen

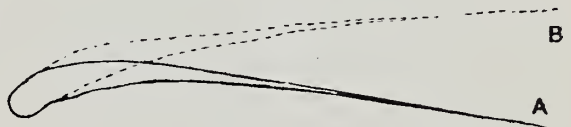


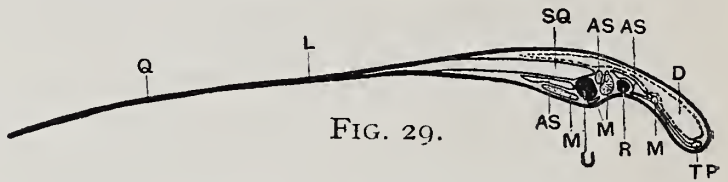
FIG. 28.

Sections of wing of an adjutant taken at junction of middle and inner thirds of the wing. For taking the sections the wing was held upside down. A weight of 10 grammes was attached to each quill feather to imitate the effect of air pressure: At A with wing extended, at B with wing flexed.

arbitrarily, but I found that a slight increase or decrease of the weight would have but little effect on the section obtained. The results on the camber are shown in figs. 28 and 29. It will be seen that with the wing flexed the camber is greatly diminished.

With the aid of the facts now described, it is possible to make a suggestion as to the nature of the adjustment by which the tractive and lifting effort of the cambered wing is put out of action in metacarpal descent.

In fig. 30 I have drawn the outline of the outer part of the wing of an adjutant as seen when it is circling in not fully soarable air. The line A is the line



Transverse section of wing of black vulture at junction of middle and inner thirds of fore-arm showing probable outline assumed when wing is exposed to pressure of the air.

- | | |
|--|---------------------------------------|
| Q. Secondary quill. | AS. Air sacs. |
| L. Posterior limit of covert feathers. | TP. Tendon of tensor, patagii muscle. |
| SQ. Shaft of quill. | M. Muscles in section. |
| D. Down, limit of which is indicated by dotted line. | R. Radius. |
| | U. Ulna. |

on a prolongation of which is the centre of effort of the cambered part of the wing; B represents the line on which is the centre of lifting effort of the phalangeal quills. Thus between A and B there is a couple tending to tilt up the wing or to maintain its angle of incidence.

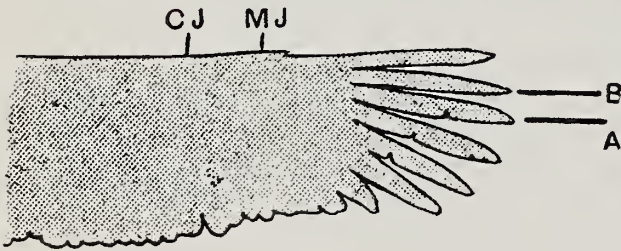


FIG. 30.

Outline of outer part of wing of adjutant when circling with effort to gain height.

- | | |
|--|--|
| A. Line on prolongation of which is centre of effort of cambered part of the wing. | B. Line on prolongation of which is centre of lifting effort of phalangeal quills. |
| | CJ. Carpal joint. |
| | MJ. Metacarpal joint. |

In fig. 31 I have represented the outline when the bird is in metacarpal descent. The wing-tip is shown retired by flexing at the metacarpal joint. The centre of effort of the cambered part of the wing is on the line A. The centre of effort of the wing-tip is on the line B. But as this line by the retirement has been displaced backwards, instead of a couple tending to

maintain the tilt of the wing, there is a couple tending to decrease its tilt. That is to say, the new position of the wing-tip results in a tendency to diminish the angle of the incidence of the cambered part of the wing.

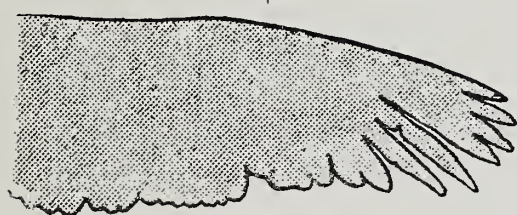


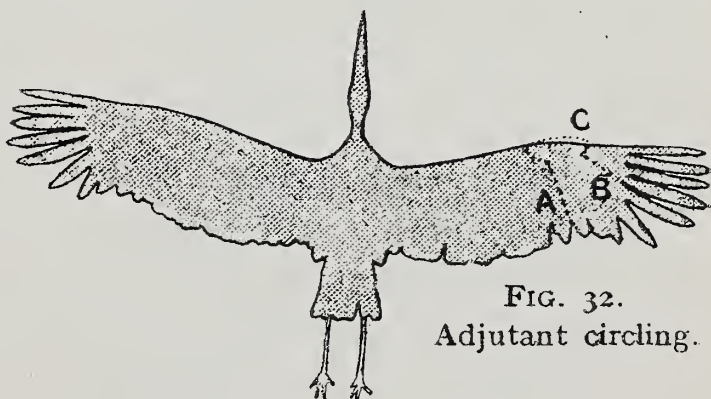
FIG. 31.

Outline of outer part of a wing of an adjutant when in metacarpal descent.

A. Line on prolongation of which is centre of effort of cambered part of the wing.

B. Line on prolongation of which is centre of lifting effort of phalangeal quills.

metacarpal descent, it has changed from a mode of flight in which it takes energy from the air to a mode of flight in which it no longer takes energy from the air. The only known change in the disposition of the wings is the retirement of the wing-tips. If the wing no longer takes energy from the air it is difficult to imagine that its angle of incidence is the same

FIG. 32.
Adjutant circling.

A. Dotted line indicates junction of secondary and metacarpal quills.

B. Indicates junction of metacarpal and digital quills.
C. Outline of alula.

as before. As may be observed, the angle of incidence is certainly not increased. It is therefore probable that retirement of the wing-tip either facilitates, or more probably causes, a decrease of the angle of incidence.

When descending in a strong wind another mode of descent may be adopted. Flexing of the wings is increased to a greater extent than that usual in fast flex-gliding. The bird accordingly drops through the air feet foremost with the flexed wings extended horizontally. The alula is usually advanced. This mode of descending may be termed "carpal descent." At the end of a metacarpal descent, when speed has sufficiently diminished, there is often a change to carpal descent by further flexure of the wings. I shall describe cases of carpal descent in detail on a later occasion.

The smaller birds frequently descend by a method of a totally different nature, namely by increasing the angle of incidence without change of course. On a later occasion I shall describe the

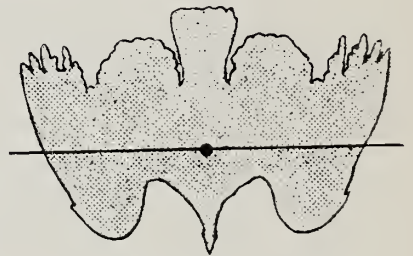


FIG. 33.

Outline of a vulture when diving. Span when wings extended, 85in.; span when diving, 40in.; weight of bird, 5,520 grammes. The transverse line is drawn through the centre of gravity.

nature of the adjustment by means of which this change of disposition of the wings is produced.

In carpal descent flexing is chiefly at the carpal and elbow joints. In another form of descent, to be described later, the wing is retired by movement at the shoulder joint (= "shoulder descent"). In diving flexing also occurs at the shoulder joint, besides at other joints, thus bringing the greater part of the area of the wings behind the level of the centre of gravity, as shown in the accompanying fig. 33.

These different forms of descent will be described in greater detail and their purpose explained on a later occasion. It is frequently very difficult to distinguish

between them. Different modes of descent also may be combined. Metacarpal descent is employed when the bird is descending at leisure. Other modes of descent are employed when the bird is descending in a hurry, as when attracted by carrion. In Agra vultures commonly come to roost on trees two or three miles away from the Jharna Nullah Factory. Their descent on these occasions is not easy to study, as if they see me standing with my binocular near a tree they are apt to misunderstand my interest in their movements, and descend to a tree a mile or more away.

In my notes I have stated that steering during metacarpal descent is by dip movements of the wing-tips. At the time however of recording this opinion I was not aware of the existence of all the different modes of descent in use, and may have mistaken shoulder for metacarpal descent.

The importance of the power of changing camber for flight will be apparent in later chapters. On another occasion I shall have to describe the very different mechanisms for changing camber employed by bats and flying-fishes.

We have already (Chapter VI.) described steering movements of the inside wing-tip in circling. Our knowledge of the nature of the mechanism for changing camber puts us in a position to understand certain obscure movements of the outside wing-tip which are very difficult to observe.

An example of my first observations relating to this matter is the following :

March 7th, 1910. Agra, at 1.0.—A large group of vultures circling in Taj Gunj direction. They were from 100 metres up and upwards. Several showed windward dip strongly marked, and also slight arching of outside wing on the windward side of the track.

At first I regarded this movement of the outside wing as identical with the arching that I had already observed in cheels. But I gradually noticed that this arching, unlike that of cheels, only affected the outer part of the wing. Then, as I became more familiar with the appearance, I recognised that this false arching was of the nature of a "half-dip movement." But it was only when I arrived in Naini Tal that I was able to make conclusive observations that showed that the false arching in question was of the nature indicated.

The following are examples of my Naini Tal observations :

June 19th, 1910, at Ballia Ravine. At 12.30.—A black vulture circling showed windward dip—that is to say, of inside wing—on windward side of track. This was seen to be followed by a slight half dip of outside wing.

June 22nd, 1910, at Ballia Ravine. At 3.45.—A vulture circling with wings nearly flat showed windward dip followed by a half dip of the outer wing. This was again seen shortly afterwards. There were a few small cloud shadows. I formed the impression that vultures circling in sunshine had wings dihedrally-up, while the one or two vultures seen circling with wings flat were in shade.

At Ballia Ravine I noticed that in circling, besides windward and leeward dips, other small dip movements of the inside wing occasionally occurred. In addition the windward and leeward dips were often followed by slight dip movements of the outside wing-tip. These usually last longer than the previously described movements of the inside wing. A half-dip of the outside wing may last for several seconds.

These movements of the outside wing-tip occur more frequently than otherwise on the windward side of the track, *i.e.*, at that portion of the circle where there is most canting, and presumably most steering. That is to say, the outside wing-tip is occasionally rotated downwards at a time when it should be rotated

upwards, if Wright's method played a part in steering movements.

But the movement of the outside wing-tip does not seem to be, or always to be, simply a half-dip movement. Occasionally at least, it is combined with slight retirement of the digital quill feathers. This gives the wing-tip a rounded appearance. For instance :

August 17th, 1910, at Jharna Nullah. At 11.50.—Sunshine increasing, and circling of larger birds beginning. Adjutants circling with occasional flapping. Light wind. Some adjutants circling showed clearly rounding of outside wing-tip on windward side of track. This was seen three times. Twice also a very slight rounding, merely a slight retirement of the first digital quill, was observed.¹

12.6.—Adjutants circling overhead a short way up showed half dip of outside wing along windward side as a depression of first digital quill only. This was often combined with a slight retirement of this feather. This latter movement (extent probably about an inch) was presumably an indication of very slight relaxation of secondaries. It could only be seen when the birds were directly overhead or slightly to windward. As soon as they had drifted past to leeward, the quill feathers seemed to approximate, owing to their being seen foreshortened.

12.50.—Two miles along Tundla Road, beyond Jharna Nullah. An adjutant circling, in nearly complete calm, and well canted over, showed on each of several circles observed, slight advancing of alula (perhaps a little more than half an inch) of inside wing on up-wind side of circle. While I was watching it the wind increased. The bird then circled with its wings not quite fully extended. No advancement of the alula then occurred. The bird was not so canted as previously. Presumably it was ease-circling. The advancement of the alula, when it occurred, was quite definitely and clearly seen. The bird showed scarcely any leeward drift, so there could not have been much wind at the height at which it was circling.

On one other occasion I have seen advancement of the alula in an adjutant.

The above is the only instance in which I have definitely noted in my diary that the wing-tip was retired during the half-dip of the outside wing. It must be obvious that both these movements are very difficult to see. The retirement is best seen when the bird is

¹ No doubt the succeeding three digital quills were also retired. But it was only in the case of the first quill, thanks to its position, that the movement could with certainty be distinguished.

directly overhead. The dip, on the other hand, would be more easily observed when the bird is seen from the side. But the following instance suggests that the two movements are combined :

November 13th, 1910, at Jharna Nullah. 9.53.—Vultures began circling.

10.14.—Vultures began slow flex-gliding.

10.24.—No half dips or retirement of outside wing-tips have been seen as yet, though I had looked carefully for these movements.

10.30.—Besides columns of birds circling and drifting to leeward, vultures were now circling without leeward drift over the slaughter-house. Previously, all circling vultures had shown leeward drift.

10.33.—Vultures seen flex-gliding at medium speed.

10.35.—A vulture seen fast flex-gliding.

10.46.—Many, perhaps a hundred, vultures started to windward of me and drifted overhead at a height of 20 or 30 metres. They were gaining height rapidly. They showed many half dips and retirement of outside wing-tips. These occurred both on windward and leeward sides of the circle. They were seen in every vulture that could be observed.

11.32.—Vultures now were circling for the most part with wing-tips of both wings slightly retired. This is ease-circling. It had not been observed previously. But vultures at lower levels were circling with wings slightly advanced or straight (tips not retired), and occasionally flapped.

A long time before making these observations, I had noticed in circling vultures that the quill feathers of the outside wing-tip were occasionally not as fully extended (that is to say, advanced) as those of the inside wing-tip. I was at first of opinion that this was a sign that the outside wing did less work in circling, and that consequently the bird did not find it necessary to use the muscular exertion necessary for full extension. In view of the facts now described, it appears more probable that this lack of full extension is a sign of slight decrease of camber of the outside wing, which decrease, it may be surmised, is favourable for the relatively greater speed of the outside wing when the bird is travelling on a curved course. When describing my observations in Naini Tal I mentioned certain cases

in which I was able to see a decrease of camber of the outside wing in circling, as evidenced by a slight relaxation of the secondaries. Presumably these cases were of half-dips with retirement of the outside wing-tip. The fact that while observing the relaxation of the secondaries I made no note of any movement of the wing-tips proves nothing. The relaxation was so very difficult to see that all my attention must have been concentrated on the hind margins of the two wings. Small movements of the wing-tip may well have been occurring at the time.

Thus the exact nature of the movement of the outside wing-tip in circling is still a matter of inference rather than of observation. If I am right in supposing that the wing-tip retirement is due to carpal and not to metacarpal flexing, then perhaps the movement is some kind of adjustment for steering in a direction opposite to that which would be produced by a full-dip movement of the same wing. For instance :

September 4th, 1910, at Jharna Nullah. At 11.3.—A vulture seen to change from slow flex-gliding to circling by retiring of outside wing-tip. No dip of inside wing took place.

The facts hitherto brought forward make it probable that birds possess two distinct methods of steering in the horizontal plane. Facts to be described in Chapter X. will be found to prove definitely that this is the case, and to suggest a simple explanation as to why two methods of steering are required.

CHAPTER VIII.

ARCHING. FUNCTIONS OF THE TAIL.

Concavity of the bird's wing in the fore and aft direction is known as camber. Concavity in the lateral direction, or from side to side, I propose to term "arching." I have already used the term "flat" to describe the position of the wings when they are in the same straight line with one another, *i.e.*, when there is no dihedral angle. I therefore propose to describe a single wing as "even" if, when seen from behind, it lies in one plane and shows no arching.

The wings of the cheel when ease-gliding are sometimes arched and sometimes even. Certain facts suggest that the even position of the wings is that of greatest efficiency for obtaining energy from soarable air. Hence this disposition is not likely to be assumed unless a sufficient supply of air energy is available. Very often, perhaps more often than not, in the case of cheels it is difficult to say whether the wings are arched or even as one is generally not in a sufficiently good position for observing.

On one occasion at Jharna Nullah, in April 1910, I noticed that before the air became soarable cheels in flap-gliding flight held their wings in a slightly arched position during the periods of gliding. When circling commenced the wings were held completely even, either flat or perhaps occasionally slightly dihedrally-down. Within a minute the wings, still even, could be seen occasionally to assume the dihedrally - up position. About two minutes later ease - circling had com-

menced, and the wings were frequently seen to be strongly arched.¹

On only one or two occasions have I been able to see arching of the wings of vultures in Agra. On the other hand, at Ballia Ravine in Naini Tal perhaps owing to better opportunities of observation, I was able frequently to see it, both in the case of the common (white-backed) and in the case of the brown vulture. The appearance in these two species of vulture is shown diagrammatically in fig. 34.

These vultures when starting usually glided horizontally for some way down the valley, on the rising

A. Of common or white-backed vulture (*Gyps bengalensis*).

B. Of brown vulture (probably *Gyps indicus*).

A has a tail at a lower level than the wings.

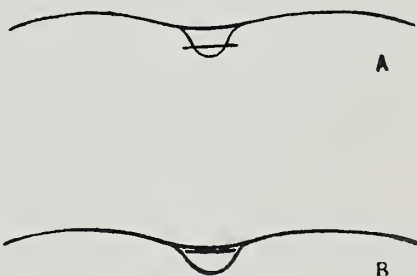


FIG. 34.

Diagrammatic end-on view, showing arching in vultures.

current of air, with their wings arched. After thus travelling for several hundred metres, it was a common observation to see the wings suddenly assume the dihedrally-up position, and to become even. This change was at once followed by a gain of height, after which the bird commenced circling.

¹ Observations have been carried out daily during April and May, 1912. During this time I have never seen the even position used until the air was on the point of becoming soarable for cheels. In fully unsoarable air cheels when gliding always use the arched disposition. In order to learn the true "gliding angle" of a cheel, observations should be carried out on cheels in unsoarable air with wings arched. If the sudden loss of height that occasionally occurs in lift-gliding is due to the bird reaching a patch of unsoarable air, and not making the necessary wing dispositions to cope with it, then it appears to follow (owing to the steepness of descent observed under such conditions) that the even disposition with wings extended is one in which the gliding angle is bad, apart from the air energy used in soaring flight. In flap-gliding flight, in returning to roost at night, the wings are usually flat. In this case, as elsewhere explained, loss of height is avoided by sacrifice of speed. This line of argument is obviously based on probabilities rather than on certainties. That is to say, in view of the varying nature of the air, and in view of the varying wing dispositions employed, it is very difficult to discover by observation the gliding angle of a soaring bird.

The following observations are examples of arching in vultures observed in Agra :

12th November, 1910, at Jharna Nullah. At 3.20.—A vulture when descending showed arching lasting for several seconds. When near the ground it dropped by carpal descent. Probably it used this method of descent because at the time the wind was rather strong. Another vulture descending by a similar method seen at 3.54.

August 2nd, 1910. At 4.—A brown vulture seen circling downwards from a height of perhaps 800 metres to a height of perhaps 400 metres. After this descent it ease-glided horizontally with wings arched. Then it turned slightly in its course, and while still travelling horizontally, its speed was seen to increase. It was then seen to be flex-gliding. I did not observe a double dip at the commencement of this change to flex-gliding, and doubt whether such movement occurred.

Observations that I have carried out on adjutant birds and flying-foxes show definitely that arching involves a decrease of lifting efficiency in these animals. It will be sufficient for my present purpose to quote in detail my observations on adjutants.

Two adjutants that I shot had the following measurements :

A.				B.			
Span	..	..	9ft.	Span	..	..	9ft. 2in.
Width of wing	..	..	1ft. 3in.	Area of one wing	..	..	4.85 sq. ft.
Length of wing	..	..	4ft.	Area of wing tip	..	..	1.85 "
Weight	7,344 grammes = 16.86 lbs.			Area of digital			
Area of both wings	..	..	10.5 sq. ft.	quill mass	..	..	.71 "
Loading per sq. ft. of				Area of one secondary			
wing area	..	..	1.54 lb.	quill	..	..	.166 "
				Area of one secondary			
				quill not overlapped			
				by its neighbour			
				(i.e., exposed direct-			
				ly to air pressure)	..	..	.105 "

In most respects the flight of adjutants resembles that of vultures. They circle with vultures, and may be seen flex-gliding. In the flex-gliding position the wings are usually not quite so much flexed as in the case of vultures, but the difference between the circling and the flex-gliding disposition of the wings is quite easy to recognise.

But their flight differs from that of vultures in the use they make of arching. Arching the wings in the case of a vulture merely seems to result in decrease of efficiency. In the case of the heavier adjutant, arching the wings results in immediate descent. Arching is the method of descent employed by adjutants in a strong wind or when for any reason they are in a hurry. If an adjutant is watched gliding horizontally, its wings will be seen to be even and set at a slight dihedrally-up angle. If it then places its wings in the arched position it immediately begins to glide downwards. Increasing the amount of arching hastens the rate of descent. If when gliding with wings even one wing is momentarily arched that wing descends, giving the bird a canted position. If an adjutant is already canted then momentary arching of the upper wing will cause it to come to an even keel.

August 14th, 1910, at Futteypur-Sikri. At 1.15.—A bird, probably an adjutant, perhaps a crane, descending from about 700 metres to perhaps 400 metres height, showed arching and head raised during part of its descent, besides legs being partly dropped. The bird then drew up its legs and flex-glided away.

It is obvious that raising the head must affect the position of the centre of gravity, and possibly the object of this movement is to produce some change in the position of this point.

FIG. 35.

Adjutant seen from behind, with wings arched and legs hanging down.



The amount of arching shown by adjutants in descending is greater than I have observed in ease-gliding vultures. The appearance in end-on view of an adjutant with wings arched is shown diagrammatically in fig. 35.

Steering in the horizontal plane when the wings are arched is effected by what is apparently a dip movement of the inside wing. There is an appearance of the wing-tip being twisted, but the result resembles an increase of arching.

The following is an example of momentary arching of the upper wing being used by a vulture to remove canting:

August 30th, 1910, at Jharna Nullah. At 5.10.—Clouding over. All adjutants settled and vultures descending. A vulture gliding downwards in a canted position arched its upper wing momentarily. Thereupon the amount of canting greatly decreased. The movement observed must have been arching, and not a wing depression, because as the bird diminished its canting, it turned and glided off to the left. Had the movement been a depression, the turn would have been to the right.

The question arises what is the nature of arching? I have a rough acquaintance with the direct or immediate action of all the intrinsic muscles of the wing of an adjutant. I am therefore able to assert that there is no muscular mechanism capable of producing the arched position by any direct action. The facts concerning arching are firstly, that the wings make a dihedrally-up angle with each other as they leave the body and secondly, when arched, the air does not impinge on the under surface of the digital quills. That is to say in the arched position the wing-tip has been rotated. Rotation of the wing-tip only, when the wings are dihedrally-up, would merely produce an appearance of a dip of the wing-tips as I have had occasion of observing. Hence it appears probable that arching is produced by slight rotation of the whole wing while it is in the dihedrally-up position. In other words it is probable that arching is a position in which the angle of incidence of the wing is diminished. In later chapters I shall describe other modes of descent in which there is also a change from the normal angle of incidence.

In the case of the flying-fox there is a muscle which by direct action can produce arching by bending the outer part of the wing downwards at the carpal joint. Observations have led me to believe that in this animal also there is a decrease in the angle of incidence in the arched position.

It will be convenient at this point to consider the question of the functions of the tail. Lilienthal says: "As compared with the action of the wings, the tail surface of birds has only a very small importance, since the bird flies very nearly as well as before after loss of the whole of the tail feathers. This is the case not only as regards turning upwards and downwards, but also as regards steering in the horizontal plane. A sparrow deprived of its tail flies just as adroitly through a lattice as its intact brother." In order to discover the functions of the tail of birds, it is necessary to discover exactly in what respects the flight of the tail-less bird is defective.

During the cold weather of 1909-10, several cheels were known to me by sight whose tails were more or less mutilated. The tail feathers of one, or perhaps two cheels, were entirely missing. Another had tail feathers about $\frac{1}{2}$ in. long. Another had only a single tail feather, which however was stripped entirely of its barbs, and resembled a bristle of about 3 in. in length. Another had a single tail feather on each side. Another lacked the whole of the tail feathers on one side of the tail. I propose to refer to these mutilated birds collectively as "tail-less cheels." I was so fortunate as to discover the conditions under which their stability is defective.

Elsewhere I have described as "tail-jolting" somewhat rapid up and down movements of the furled tail

of the cheel, which have to do with maintenance of equilibrium round the transverse axis. I have on rare occasions seen similar movements in the case of the lammergeyer, the black vulture, and the common vulture, usually when gliding in disturbed and stormy winds. Tail-jolting movements are shown by tail-less cheels in the sense that the posterior portion of the body may be seen to be jolted up and down. Tail-less cheels under all conditions at first sight appear to have as much stability round the transverse axis as tailed cheels. Occasionally however in irregular winds they make double-dip movements more energetically than tailed cheels.

The fact that tail-jolting as above described occurs in tail-less cheels accords with my suggestion that this adjustment acts by altering the position of the centre of gravity, and has nothing to do with the pressure of the air on the surface of the tail feathers.

We have now to consider the functions of the expanded tail, when as we shall see there is reason for believing that air pressure on the surface of the tail comes into play.

The long axis of the tail is a continuation of the long axis of the body. When the tail is furled the tail feathers lie close together and parallel to this long axis. When the tail is expanded the tail feathers come apart like the ribs of a lady's fan. The expanded tail can be rotated to and fro round its long axis. It is necessary to discover the meaning of this movement.

So far as I am aware, all birds usually expand the tail when settling in a calm or a light wind. In fig. 21 I have already shown the aspect of the tail of a green parrot when stop-flapping. The tail feathers are seen to

be widely expanded. When the bird is settling, the tail besides being expanded, is depressed, so that its surface lies nearly at right angles to the direction of movement of the bird. For instance :

June 17th, 1910, at Ballia Ravine. At 2.46.—A crow seen descending. Its tail was furred and raised. Immediately before perching it expanded and depressed its tail.

A tail-less parrot is known to me by sight. When in flapping flight in company with other parrots it shows no lack of stability or of power of guiding its movements. On one occasion I happened to see it perching. As it caught hold of the bough with its feet it seemed nearly to tumble over backwards; that is to say, there was too much rotation round the transverse axis.

These facts suggest that in perching the expanded tail acts as a brake principally for checking movement round the transverse axis. Rotation round this axis is produced by advancing the wings and checked by expansion of the tail. The depressing of the expanded tail may also help to check the forward movement of the bird through the air.

Expansion of the tail, in the case of pigeons and swifts, is used to assist in checking speed in gliding flight. At the same time the wings may be seen to be placed dihedrally upwards. In some cases the dihedral angle may be nearly as much as 45° . This adjustment tends to produce rotation upwards round the transverse axis. The expansion of the tail tends to check this rotation. The two actions, together with the decrease in supporting area of the wings, result in a decrease of speed.

We have now to consider the function of the tail in relation to stability round the dorso-ventral axis.

In certain winds tail-less cheels may show more instability round this axis than complete cheels. I have

observed this especially on the windward side of the Fort walls where the cheel was exposed to the influence of currents ascending at various angles with the horizon.

The following are examples of my observations on cheels gliding on the windward side of the Fort walls :

May 29th, 1910, on Strand Road outside and below Fort battlements. From 6.30 p.m. onwards.—Wind east, for the most part light, just moving leaves. Many cheels and one or two scavengers over the battlements. Tail-less and short-tailed cheels all appeared nearly stable round dorso-ventral axis. Cheels kept their tails furled except sometimes when gliding low just over battlements and when gliding to leeward. When just above battlements the tail-less cheels seemed unsteady round dorso-ventral axis. During a light puff of wind many cheels remained wind-facing almost fixed in position. Others, and also the tail-less cheels, glided to and fro above the battlements at right angles to wind direction. At the end of their course the tail-less cheels turned just as easily as the others, using wing depressions. Both cheels and scavengers were noticed to increase flexing of wings to increase speed, *e.g.*, one cheel chasing another, a cheel chasing a hawk, or in response to a puff of wind. As the wind was easy tail-less cheels were able to glide up to the front of the group of birds. This was noticed three times at least. When directly overhead, instability round the dorso-ventral axis was noticed. During a puff of wind, when wings were much flexed, a tail-less cheel appeared to have alulæ extended. (I believe this adjustment might, under similar conditions, be shown by a complete cheel.) Tail-less cheels appeared to make double dips when wind-facing more often than complete cheels. Except for slight tail-jolting, tail-less cheels were quite stable when going to leeward on a curved course. All the cheels went away between 7.10 and 7.16, when it was getting dark.

23rd April, 1912. At 5.0.—To leeward of Fort. A cheel at 30 metres height showed single wing depressions and no tail-jolting.

5.10.—On battlements by Delhi Gate to west of Fort. Wind west, moving branches occasionally. Sunshine, but thin cloud over sun. Many cheels wind-facing. They often showed both tail-jolting and dorso-ventral axis instability. Cheels at a distance of from 100 to 200 metres towards city apparently out of range of Fort wall ascending current also showed tail-jolting. These were at high level, *i.e.*, higher than the cheel seen at 5.0 to leeward of Fort. Each cheel as it came into the ascending current (when gliding to windward from the leeward side of the battlements) showed a rapid gain of height. Signs of instability at this time were not conspicuous, but were visible, especially as single wing depressions. Sometimes for some time in the rising current the tail was furled and elevated (*i.e.*, although gaining height as regards the earth the cheel in reality was gliding downwards through the rising air).

5.12.—An eagle at some distance to windward showed no tail-jolting. As it came over the battlements tail-jolting occurred.

5.19.—A cheel and an eagle as they came into the rising current, gliding obliquely from the leeward side, showed half dips of windward wing.

In this instance, it appears that the wind at low levels caused dorso-ventral axis instability, which was corrected by single wing depressions. This occurred independently of the rising current reflected upwards from the Fort walls, as shown by the observation at 5.10 p.m. The same wind at higher levels caused tail-jolting at intervals (*i.e.*, the sign of transverse axis instability), and it also did this independently of the ascending current. The observation made at 5.19 p.m. shows the adjustment used for coping with an ascending current affecting one wing before the other. The wing-tip of the first affected wing is slightly dipped, whereby the angle of incidence of this wing and its efficiency (as will be shown later) are diminished.

In light unsoarable winds cheels collect on the windward side of the Fort and glide to and fro from 1 to 5 metres above the battlements. In stronger winds, they may collect and form a column at a height of 100 to 500 metres above the battlements. In other winds, though strong, the cheels may keep nearly at the level of the top of the battlements, as instanced in the following observation :

May 7th, 1910, at Delhi Gate of Fort. At 5.45.—Wind west and rather strong. Many cheels and scavengers wind-facing. A tail-less cheel showed unsteadiness round dorso-ventral axis. A depression of the wing for turning seemed to produce more steering (in the horizontal plane) than was intended. Hence the bird had to go off on a glide to leeward. It was unable to advance as far in front of the battlements as complete cheels when wind-facing. A cheel with only one tail feather was similarly unsteady.

In a wind of this description, tail-less cheels may be seen generally on the leeward side of the cluster of birds. Any wing depression for steering seems apt to turn them too far. They may try to correct this

excessive turn by a depression of the other wing. Sometimes they succeed, but more often they turn too far in the opposite direction, and appear obliged, as if against their will, to glide off to leeward. Normal cheels, on the other hand, supported on the ascending currents, often glide to some distance to windward of the battlements. Here they may remain for several minutes at a time "wind-facing." That is they remain, generally facing the wind more or less, gliding to and fro and so adjusting their speed that they travel but slowly over the earth, and remain at almost a constant distance to windward of the battlements. Sooner or later they are turned, as if by some irregularity of the wind, and glide rapidly to leeward. Then turning, they glide up again to windward, and reach their original position. Tail-less cheels are evidently handicapped in attempting this feat. Usually they have scarcely crossed the line of the battlements when they may be seen to be in difficulties, and after a few energetic attempts to remain facing the wind, they may be seen to turn away and glide off to leeward.

When at some height above the battlements cheels usually keep their tails furled. When nearer the battlements the tails are more or less expanded. As a rule, the tail is fully expanded when the bird is making a turn, or when it is gliding away to leeward. The tail when expanded is frequently rotated to and fro round its longitudinal axis. That is to say, first one side and then the other side of the tail is depressed below the horizontal plane. The range of movement of the tail in this rotation may be as much as 30° . There is no clear and evident connection between rotation of the tail and change of course. Sometimes a cheel may be

seen with its tail strongly depressed to one side for an appreciable time, but yet the bird continues to glide in a straight line. Thus we see that a depression of one side of the tail *per se* has no steering action. Sometimes after the tail is depressed on one side there is a wing depression of the same side, to which side the cheel is accordingly steered. If this sometimes occurred, and if the alternative was that during a steering movement the tail should be horizontal, one might come to the conclusion that a depression of one side of the tail (a rotation round its long axis) was an additional movement that aids steering but that is not indispensable. But it sometimes happens that, during a turn, the tail is observed to have been rotated in the opposite direction. For instance, a wing depression of the left wing may occur and steer the bird to the left at a time when the right side of the tail is depressed.

As soon as my acquaintance with the facts led me to doubt whether rotations of the tail produce steering movements I made a point of looking to see whether in normal turns the depressing of the side of the tail was coincident with or preceded the wing depression. To my surprise, I found that the rotation of the tail, if it occurred at all, preceded the wing depression. In view of the facts described relating to tail-less cheels, there can be little doubt that the function of the tail is to act as a brake for turns round the dorso-ventral axis, and that it does so more efficiently if the side of the tail is depressed on the side of the turn. Supposing the bird commences to steer to the right, this steering tends to be checked by the tail if this organ has so rotated round its longitudinal axis that the right half of the tail is depressed below the horizontal plane.

Obviously if movements of the tail produced steering, then tail-less cheels should turn less readily than complete cheels. But, as we have seen, the contrary is the case. Hence the dorso-ventral axis instability of tail-less cheels gives strong support to the view that the function of the tail is to act as a brake in the manner described.

The numerous apparently purposeless rotations of the tail when cheels are manœuvring in complicated air currents must on this view be regarded as "anticipatory movements." They are preparations for turns that it may or may not make as it is influenced by changing air currents or the necessity of avoiding other birds.

Flying-foxes when poising before perching, may frequently be seen to advance the hind legs. No doubt this movement is preparatory to grasping the bough with their feet. But as it results in bringing the posterior part of the wing surface to a position at right angles to the direction in which the animal has been gliding, it is possible that to some small extent the action has a braking effect similar to that produced by the depressed and expanded tail of birds when perching.

It remains to consider the possibility that the tail has an action similar to the horizontal rudder of aeroplanes in steering the bird up and down. I have already stated that the tail-less cheel, in an irregular wind, may show double dips more often than complete cheels. This statement is illustrated by the following observation :

December 13th, 1910. At 11.20.—Wind rather strong, and moving branches. A tail-less cheel seen overhead about 10 metres above the tree-tops. It showed slight instability round the dorso-ventral axis. This consisted in occasional sudden turns (round this axis) through about 10° . Each time it turned back to its original position with equal suddenness

and after an appreciable pause. There was no attempt to check rotation round the dorso-ventral axis by double dips. It made double dips more often than did complete cheels that were gliding near. Its double dips seemed larger and more sudden than usual.

Though double dips were not used to check rotation round the dorso-ventral axis, it is possible, on the one hand, that such rotations caused loss of speed ahead, and hence there was the necessity for an occasional double dip to increase speed. On the other hand, it is possible that the surface of the expanded tail of the complete cheel acts, so to speak, passively in checking rotation round the transverse axis. Possibly lacking this brake, the tail-less cheel is apt to be rotated upwards round the transverse axis, and hence occasionally finds it necessary to make a downward rotation round this axis by means of a double dip. But on the other hand, there is no doubt that the tail does not actively produce rotation round the transverse axis after the manner of the horizontal rudder of an aeroplane. If it did so the tail should be depressed when the bird is gliding downwards. But as we have seen when the bird is gliding downwards the tail is furled and raised. It then acts by raising the position of the centre of gravity relatively to the centre of resistance of the wing-tips, thus tending to cause rotation downwards round the transverse axis. Conversely, when the bird is perching, it rotates upwards round its transverse axis. If the tail acted as the horizontal rudder of an aeroplane it should then be elevated; but as we have seen the expanded tail of the perching bird is depressed.

In the gliding flight of certain smaller birds, such as the dove, the tail is habitually kept expanded. In this case there can be little doubt that it aids in supporting the bird.

CHAPTER IX.

FLAPPING FLIGHT.

It will be found that the study of flapping flight throws an unexpected light on several problems connected with gliding flight.

A difficulty in understanding flapping flight lies in the fact that the bird may, at one and the same time, be making movements having different objects. For instance, movements of propulsion, movements in opposition to gravity, movements for balance, and movements for directing its course. In addition there may be movements or adjustments for checking speed independently of those used for perching.

It is necessary to find a simple form of flight in which the propulsive movement may be studied alone. This desideratum is supplied in a very satisfactory way by the poising of the pied kingfisher in calm air.

The pied kingfisher (*Ceryle rudis*) differs from other species of kingfisher in having a habit of poising in the air and then suddenly diving down head foremost on to its prey. While poising the bird appears as if fixed in one position with its wings in rapid motion. It may remain thus poised for several seconds at a time.

The following measurements were obtained from a specimen of this bird :

Weight 90 grammes, say	3 ozs.	Area of wings	..	.352 sq. ft.
Span	18in.	Loading .. ..	..	.76 lb.
Length	11½in.			

In the case of the pied kingfisher poising in still air, since the wings are propelling it vertically upwards, the propelling movement has no admixture with any other

movement or disposition for counteracting gravity. Also there are no directive movements as the bird is not travelling from place to place.

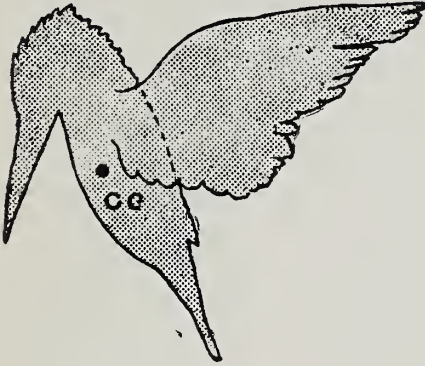


FIG. 36.

Pied kingfisher poising at commencement of down-stroke.

If a pied kingfisher is watched under these conditions it will be seen that the movement of the wings is not up and down but to and fro in a perfectly horizontal direction. It will be convenient however to use the term "up-stroke" and "down-stroke" in describing the movement of its wings.

Fig. 36 shows the position of the wing at the commencement of the down-stroke. Fig. 37 shows the position at the end of the down-stroke.

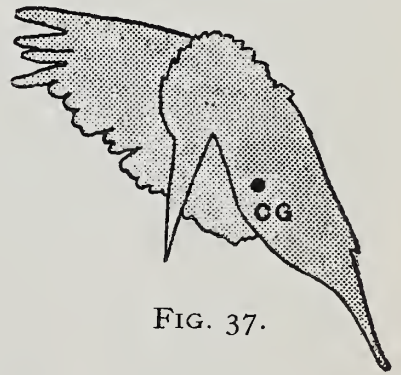


FIG. 37.

During the down-stroke, as shown in fig. 38, the wing is moving horizontally forwards.

Pied kingfisher poising at end of down-stroke.

The quill feathers, by the pressure of the air, are bent backwards. The area of the wing therefore forms a slanting surface. The pressure of the air on this slanting surface results in a component tending to lift the bird.

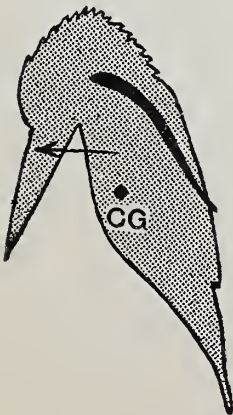


FIG. 38.

Position of wing of poising kingfisher during down-stroke.

The position of the wing during the up-stroke is shown in fig. 39. Partly owing to the pressure of the air on the feathers, perhaps partly also owing to the wing having been slightly rotated,

the area of the wing now forms an inclined plane, inclined in the opposite direction. As in the former case there is a resultant force tending to lift the bird.

Because the bird remains in the same place the lift on the down-stroke must equal the lift on the up-stroke. If, owing to its shape, the area of the wing is less efficient in lifting on the up-stroke then this lack of efficiency must be compensated by greater speed. Whether or not this is the case in the pied kingfisher it is not possible to see owing to the extreme rapidity of the beats when poising. But in the case of some larger birds, and in the case of the flying-fox, I have been able definitely to observe that the movement of the wings when in horizontal flight is faster on the up-stroke.

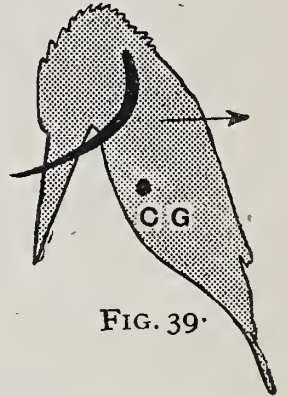


FIG. 39.

Position of wing of poising kingfisher during up - stroke.

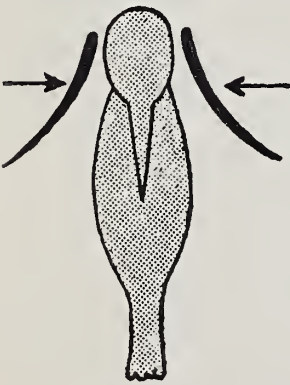


FIG. 40.

Front view of poising kingfisher near end of down-stroke.

In the poising pied kingfisher the strokes are of much greater amplitude than they are in ordinary horizontal flapping flight. At the end of the down-stroke the wings nearly meet in the front of the body. At the end of the up-stroke the wings nearly meet behind the back. Fig. 40 shows the bird as seen from in front when the wings are coming together near the end of the down-stroke. It must be obvious that the two wings, when approaching tend to squeeze out air from between them in a downward direction thereby, to a small degree, aiding the lifting effect. Fig. 41 shows the bird, again as seen from in front, when the wings are receding from one another at the commence-

ment of the up-stroke. Owing to their movement, there must be a tendency for the air to be sucked in from above, and again there is a slight addition to the lifting effect. It must be obvious from this description that the poising kingfisher resembles a horizontally placed propeller whose blades



FIG. 41.

Front view of poising kingfisher at beginning of up-stroke.

reverse every half-revolution.

Fig. 42 represents a pied kingfisher poising not in calm air but in a wind. Under these conditions the direction of the strokes of the wing is no longer horizontal but slightly inclined to the horizon. The arrow W represents the wind direction. The arrow R represents the direction of the propelling effect of the wings. As in the first case it

must be obvious that propelling work is being done on the up-stroke besides on the down-stroke.

I was once watching a pied kingfisher poising in a calm. It was struck by a puff of wind, as shown by ripples that appeared on the water below it. The consequent change in the direction of the beats of the wings could be clearly seen. Owing

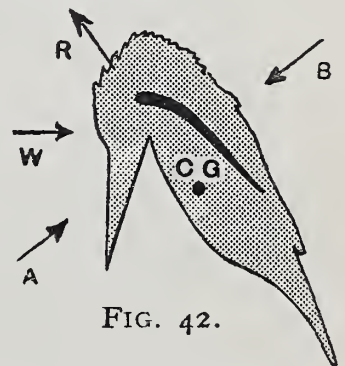


FIG. 42.

Side view of kingfisher poising in a wind. The arrows A B show direction of beat of wings, C G centre of gravity, W direction of wind, R direction of propelling force of wings.

no doubt to this change, the bird was not blown to leeward, but retained its position.

When the pied kingfisher is flying from place to place its mode of flight is quite different from that seen in poising. The long axis of the body is horizontal, or nearly so, instead of being strongly inclined as in

poising. The direction of the beat of the wings appears to be vertically up and down. The rate and also the amplitude of the beat is lessened.

So far as we have gone in considering flapping flight everything appears to be explained with one important exception, namely the adjustment by means of which the kingfisher can change from poising to cross-country flight. Obviously to do so the bird has to rotate round its transverse axis. The method of rotating round this axis previously described for gliding flight is clearly not applicable. The discovery of the method used in flapping flight is described in the following paragraphs :

It is a matter of common observation that just before perching a bird usually makes a few flaps of its wings. These flaps may seem a trivial matter to investigate, but it will be at once apparent that they are of considerable theoretical interest.

My first observation concerning this matter was as follows :

June 26th, 1910, at Ballia Ravine. At 1.34.—A vulture seen gliding up the valley to settle. When near the tree on which it was about to perch, it flapped in order to gain height or speed. The direction of the flaps could be clearly seen to be up and down. Then for a few metres it glided without flapping. Just before perching it hung down its body and again flapped. The direction of these flaps was quite clearly seen to be fore and aft—that is to say, these flaps were meant to act as a brake.

For the sake of clearness, I show these different stages in the process of settling in fig. 43. At A the bird is shown gliding. Then at B it is shown flapping with strokes apparently vertically up and down, as shown by the direction of the arrows. At C the bird is again gliding and its feet are hanging down. At D and E the bird continues to glide, but the legs and also the body are hanging down. At F the bird is again flapping,

but with the beat of the wings in a fore and aft direction. That is to say before this flapping commenced, or as it commenced, the wings rotated through a right angle. To this form of flapping I propose to give the name of "stop-flapping." In a later paragraph I shall explain the difference between stop-flapping and the flapping used by the poising kingfisher. The latter form of flapping lifts the bird. Stop-flapping, on the other hand, has no appreciable lifting effect but tends to check the forward motion of the bird through the air.



FIG. 43.

Stages in settling of a vulture. The bird is shown travelling from right to left—at A gliding, B flapping for a short distance. The arrows show the direction of the strokes. C again gliding, but with feet hanging down; D and E body beginning to hang down below level of wings; F after rotating through nearly a right angle, the wings have commenced "stop-flapping." As shown by the arrows, the direction of beats in stop-flapping is nearly horizontally to and fro.

Shortly after making the above observation I noticed a cheel settling. In this case there was no hanging down of the body before the commencement of stop-flapping. At the moment that the stop-flapping commenced, not only did the wings change their plane of action, but also there was a simultaneous rotation upwards of the whole bird round its transverse axis. How this rotation occurred was shown to me by observation of yet another cheel that did not perch by the usual method, but by the procedure shown in fig. 44. At A this cheel is shown gliding towards its perch with the wings "straight," that is to say, with their centre of effort nearly or quite on a level with their centre of gravity. The first preparation for perching made by

this cheel was to put its wings in the "advanced" position as shown at B. The bird immediately began to rotate round its transverse axis as shown at C. After the rotation had occurred, stop-flapping began, as shown at D. That is to say stop-flapping occurred with the wings in the advanced position.

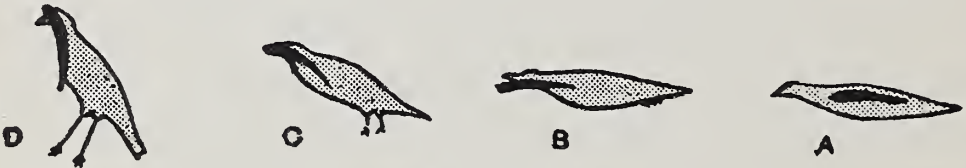


FIG. 44.

Stages in settling of a cheel. At A gliding; at B the wings are advanced, in consequence the bird rotates round its transverse axis, as shown at C; at D stop-flapping has commenced.

The explanation of this rotation round the transverse axis is both obvious and simple. In fig. 45, at A, a bird is shown with its wings in the dihedrally-up position. This, as already explained, produces a couple tending to rotate the bird upwards round its transverse axis. Obviously this result depends on the resistance that the wings or wing-tips experience to forward motion through the air. Therefore it is an adjustment that must be more efficient the faster the bird is moving. If the bird is gliding slowly, or if the bird wishes

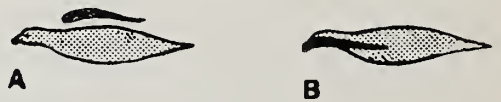


FIG. 45.

Diagram showing two methods of rotating round transverse axis. At A the wings are placed dihedrally upwards; at B the wings are shown advanced. Either disposition results in a couple tending to rotate the bird upwards (beak up, tail down) round the transverse axis.

to check its speed, a different adjustment is employed. The wings are placed in the advanced position as shown in fig. 45 at B. When in this position the wings present a resistance to dropping downwards through the air that may be regarded as concentrated at a point, which point must be in advance of the

centre of gravity. Hence there must be a couple that rotates the bird round its transverse axis. This in fact is the method used by cheels, crows, scavenger vultures, parrots, and other birds in settling either with or without stop-flapping. It is noteworthy that advancing the wings causes rotation round the transverse axis but no direct change of course. A scavenger, gliding downwards at a small angle with the horizon, may be seen suddenly to advance its wings slightly. The result is a slight rotation of the whole bird, including the wings, round the transverse axis. That is to say the angle of incidence is increased. Hence the wings act as a brake and speed decreases. As the bird gets nearer its perch there may be a further advancing of the wings. The consequent further rotation round the transverse axis acts as a stronger brake so that the bird may drop vertically on to its perch. In a slight wind an eagle for instance may stop without any stop-flapping. It is striking to see the bird gliding along at a height of 2ft. or 3ft. from the ground suddenly drop its legs and perch on a shrub or other projection without any apparent effort to check its speed beyond the advancing of the wings and expansion of the tail. While thus checking speed the tail is expanded and depressed so that its surfaces may, in some cases, be placed almost at a right angle to the line of flight. In the case of the green parrot stop-flapping always occurs and the wings may clearly be seen to be in an advanced position.

Rotation round the transverse axis may also occur when the bird is swooping downwards at high speed. If in such a case the rotation is caused by advancing the wings there is no change of course but speed is

checked. If on the other hand, in the case of cheels, rotation is caused by placing the wings in the dihedrally-up position, there is a change of course and no noticeable loss of speed. This is the adjustment used by cheels when swooping downwards to snatch a piece of food from the ground or occasionally from a tray carried on a man's head. The food is always seized by the feet. The bird swoops down, catches the food without interruption of its flight, and glides upwards almost to its original height. This curved course is due to delicately applied adjustment of the dihedral angle. On the other hand in diving as already described, placing

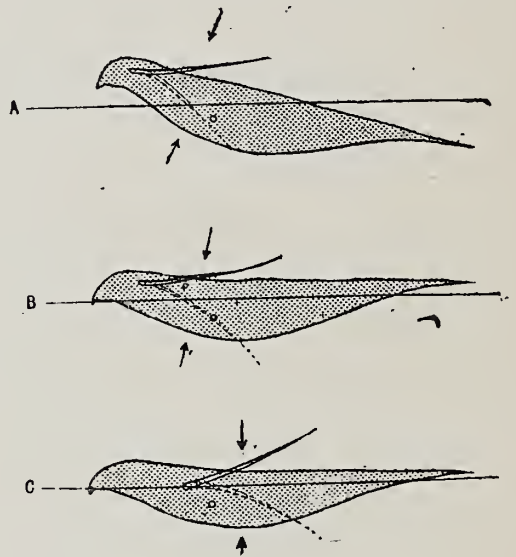


FIG. 46.

Diagram showing horizontal flapping flight at different speeds. A, slow; B, medium; C, fast. The arrows show the direction of beat of the wings. Note that the slower the flight the more are the wings advanced. The cause of this will be explained in Chapter XI. In each figure the wing section drawn as a continuous line represents the disposition during the down-stroke. The dotted line represents the disposition during the up-stroke. B may be taken to represent the ordinary flapping flight of the larger birds. C is only seen in fast flight of small birds.

the wings suddenly and strongly in the dihedrally-up position causes a sudden rotation and consequently acts as a brake. Another case in which the dihedrally-up position acts as a brake has been described in the chapter on the functions of the tail.

Conversely, flapping with the wings retired must cause rotation round the transverse axis in the opposite direction. This in fact corresponds with my observations. I have been able to see both in the case of

pigeons and green parrots, when flying downwards, that their wings are flapped in the retired position.

In slow horizontal flight the wings are flapped in a more advanced position than in fast horizontal flight. Hence in slow horizontal flight (fig. 46 A), during the down-stroke, the wings move downwards and forwards. In fast horizontal flight this forward trend of the wings on the down-stroke, if it exists, is too small to be observed (fig. 46 C).

In the case of the adjutant, I have been able to observe the change from flapping with wings advanced to flapping with wings straight. The following is an extract from my diary :

August 8th, 1910, at Jharna Nullah. At 6 p.m.—About 200 adjutants were settled. No birds up, not even cheels, except a few birds in flapping flight, mostly when disturbed. The air was nearly calm, after a succession of showers. Sound travelled far. The noise made by the beats of the wings of adjutants and vultures, if they started flying, could be clearly heard, even when the birds were at some distance from me. I sent a boy to start the adjutants. This he did cleverly in such a way that they got up, generally one at a time, and flapped past me broadside on. I thus observed the movements of between fifty and one hundred of these birds under very favourable conditions. The advance of the wings on the down stroke was clearly seen in adjutants in horizontal flight. In the case of an adjutant that was flying upwards at an angle with the horizon, the advancing was still more marked, so that the direction of the beats was nearly horizontal. After they had flapped to a height of between 10ft. and 15ft., several adjutants were seen to commence gliding. The last two flaps before gliding were, in each case, directly up and down without any advancing on the down stroke.

The following observations are of importance :

September 25th, 1910, at Jharna Nullah. At 10.30 a.m.—An adjutant flapping with wings advanced was seen to change to straight up and down flapping as a preparation for gliding. At the moment of this change, rotation downwards of the body of the bird round the transverse axis was clearly seen. This rotation may have been about 5° . An adjutant gliding downwards at a small angle with the horizon was seen to change its direction, and glide slightly upwards for several metres before commencing flapping flight with wings in advanced position. The difference between the two directions may have been as much as 10° .

In these cases the transverse axis rotation caused by changing the wings from the advanced to the straight position was actually observed.

Cheels when gliding are often followed and teased by crows. Under these conditions, to escape the crows, they sometimes make a sudden flap, which changes their direction, causing them to rotate on the transverse axis and glide upwards. At other times they make a flap which changes their course to a downward direction. At the time of first seeing this I was unable to understand how a beat downwards of the wing could cause the bird to travel downwards. Now it must be clear in this latter case the wing was flapped when in the retired position.

The following observation also receives an easy explanation:

July 5th, 1910. At 5.9.—A stormy soarable wind. A cheel seen gliding up-wind about 3 metres above the roof of my house where I was sitting. Three crows were in attendance teasing the cheel. The cheel was gliding with wings flexed, and the wings were seen to be frequently advanced or retired. Each movement which affected both wings equally, whether forward or backward, shifted the wing-tips about half an inch from their normal position.

In the light of our present knowledge, it appears probable that the advancing and retiring of the wings were movements preparatory for flapping in either an upward or a downward direction. This is an example of an "anticipatory movement."

The method of producing rotation round the transverse axis by varying the dihedral angle of the wings has not, I think, been described before. On the other hand rotation by advancing or retiring the wings has been noticed by other observers. For instance, Lilienthal says: "Accordingly the bird can easily do without its tail, as it possesses another highly efficient

means of rising or sinking in the longitudinal direction. In order to be raised longitudinally, it is only necessary for it to shift forward its wings, and so to advance their centre of supporting effort. Similarly, by drawing its wings backwards, the front part of the bird sinks. This latter movement is used by birds of prey when diving from a height.”—*Der Vogelflug*, page 73.

The facts to be described in the succeeding paragraphs will be found to give an answer to the important question as to what is the cause of the difference between lift-flapping and stop-flapping. In each case the direction of the strokes is horizontally to and fro. In the case of lift-flapping of the poising kingfisher work is done both on the up-stroke and on the down-stroke. In the case of stop-flapping there is no demonstrable lifting effect, and work appears to be done on the down-stroke only, and is in such a direction as to tend to check the forward progress of the bird.

If there is a resemblance between the action of the wings of the poising kingfisher and the action of the wings when in horizontal flight then



FIG. 47.

Pied kingfisher in fast horizontal flight, showing position of a section of a wing during the down-stroke.
C G, centre of gravity.

certain consequences must follow. Firstly, during the down-strokes in horizontal flight there must be some yielding of the hinder part of the wing area. That is to say, when the wing is being moved downwards, its surface cannot be perpendicular to the air against which it presses. It must have such a position that the wing, when descending forms an inclined plane and hence drives the air backwards besides downwards. The presumed disposition of the wing on the down-stroke is shown in fig. 47. Secondly, during the up-stroke, as

shown in fig. 48, the wing must bend in the opposite direction. As a matter of fact, the secondary quills are attached to the wing bones in such a way that they easily yield to the air pressure during the up-stroke, under all circumstances. I have once or twice observed a vulture flapping towards the west in the afternoon, and noticed that during the up-stroke the sun illuminated the underside of the wings. During the down-stroke the underside of the wings remained in shadow, thus proving that there is a difference in the inclination of the wings during the up and down-strokes of the nature above suggested.

But it has already been shown that the secondary quill feathers are so attached that they do not yield on the down-stroke if the wing is fully extended.



FIG. 48.

Pied kingfisher in fast horizontal flight, showing the position of a section of the wing during the up-stroke.

Therefore, if horizontal flight resembles poising in the manner suggested, ordinary horizontal flapping flight must take place with the wings not quite fully extended. The following extracts from my diary show that some practice was necessary before I was able definitely to determine that this is the case. The first quotation is a continuation of my observations made on August 8th, 1910:

"I looked carefully to see whether the wing (of adjutants) was fully extended during flapping flight. I was able to see that at the top of the stroke the primary quills were not so fully extended as they are in circling. Probably the first primary quill could have been advanced about 2 in. more than was the case. I saw also, but with less certainty, this lack of full extension at the bottom of the stroke. It was to the same amount as at the top.

August 12th, 1910, at Jharna Nullah. At 5.15.—Three adjutants flapping showed all through both up and down strokes the wing-tips less than fully extended. Adjutants flap-gliding, with gliding intervals

of only one or two seconds, did not make vertical up and down strokes before the glide. Wind west, moving leaves. Heavy clouds. No birds up except in flapping or flap-gliding flight.

August 14th, 1910, at Futteypur-Sikri. At 8.45.—A black vulture passed near flap-gliding. When flapping, its wings were less than fully extended by about 3 in. During the periods of gliding its wings were fully extended.

August 27th, 1910, at Jharna Nullah. At 11.50.—An adjutant seen making "half-flaps" (*i.e.*, flaps of less than usual amplitude) while circling. It was noticed that during the half-flaps the wings were not fully extended. While gliding round the rest of the circle, the wings were fully extended.

At 12.0.—Adjutants flap-gliding at low level. When flapping their wings were not fully extended. At the moment that flapping ceased, to commence a period of gliding, a sudden extension of the wing-tip was observed. In the case of adjutants flap-gliding at a higher level, this extension could not be seen, as they glided (presumably in more soarable air) at higher speed with wings slightly flexed.

12.6.—A vulture flapping. A sudden extension of the wing-tips seen as it commenced to circle.

Since making the above observations it has become quite easy for me to see the retirement of the wing-tip in flapping flight of cheels, vultures, and other birds.

The above is an example of a case in which by practice I learnt to make an observation with ease that at first could only be made with difficulty. In such cases it has more than once happened that with increased power of observation I have arrived at quite unexpected results. This is exemplified in the present case by the following observations:

September 24th, 1910, at Jharna Nullah. At 11.45.—Several vultures and three adjutants circling. They flapped occasionally when at low level. Weather fine. From 1.0 p.m. onwards there were small isolated cumulus clouds. A vulture flapping directly overhead, a few metres up, showed its wings during the up-stroke less flexed than during the down-stroke. A minute later this was more clearly seen in the case of another vulture, whose wings were more flexed than usual during the down-stroke. Shortly afterwards I saw the same phenomenon in an adjutant; but in this case the flexing seemed gradually to decrease during the up-stroke, and was followed by sudden flexing at the commencement of the down-stroke.

October 6th, 1910, at Sekundra Road Refuse Pits. At 11.5.—Adjutants starting. At first flap-circling. Then in a minute or two circling. After a few minutes slow flex-gliding.

11.20.—Adjutants fast flex-gliding. The wing-tips were retired perhaps as much as 45° with the front line of the rest of the wings. The speed was 7 metres per second against a rather strong wind. This was at a height of 300 metres.

11.26.—An adjutant noticed circling with wings slightly advanced. (Presumably circling had hitherto taken place with wings straight. The advancing is a sign of increased soarability of the air.)

11.27.—An adjutant, starting, flapped past me at a height of about 5 metres over my head. It showed clearly the wing-tip extending during the up-stroke, and the sudden flexing at the beginning of the down-stroke.

This advancing of the wing-tip during the up-stroke appears to be a matter of interest. As to its cause there are two possibilities. Firstly, it may be due to direct muscular action of the intrinsic wing muscles. If this were the case, then the extra extension must be advantageous; that is to say, the extension must aid the wing doing work during the up-stroke. Secondly, it is possible, and more probable, that the extending is not due to muscular action, but to the effect of air pressure on the upper surface of the secondary quills. As a matter of fact in the dead bird pressure on the upper surface of the secondary quills causes extension of the wing-tip. There is also the possibility that the extension during the up-stroke is due to centrifugal force. But at all events, this extension can only occur if there is a change in the position of the secondaries, such as may be caused by pressure of the air.

I have long been acquainted with the fact that the wing of the crow does not appear to move vertically up and down during fast horizontal flight. The tip of the wing as compared with the base of the wing appears to move in an ellipse whose long axis is nearly vertical. This appearance cannot, in my opinion, be explained by the above observations on adjutants. In the case of the adjutant the extension can only be seen when the bird is flapping overhead at quite a short

distance. Even then the observation can only be made after practice. It is extremely improbable that extension on the up-stroke, should it occur, could be seen in so small a bird as the crow. The appearance must have some other cause.

The facts described in this chapter appear to leave little room for doubt that in horizontal flapping flight a propelling effect results from both the up and the down-strokes of the wing.¹

In stop-flapping it is advantageous that the wings during the down-stroke should get as much grip on the air as possible. Hence, as can be very easily seen, in stop-flapping the down-stroke is made with the wings fully extended and consequently with maximum camber. An illustration of stop-flapping, showing the full extension besides advancing of the wings in the case of the green parrot, has already been given in fig. 21.

During the up-stroke in stop-flapping the wings also remain fully extended. As already explained this full extension does not prevent the secondary quills yielding to the pressure of the air. Hence, if the preceding was the only evidence available we should have to conclude that lifting work was done during the up-stroke. But the following observations show that certainly in some cases, possibly in all, no lifting work of this nature is done.

September 20th, 1910, at Jharna Nullah. At 5.15.—Slight cloud. All birds settled except cheels and eagles skimming over the buildings. Some adjutants on being disturbed flapped across a shallow ravine. One turned slightly while over this ravine to settle on a wall—that is to say, it had to lose speed more quickly than would have been the case had it been alighting on level ground. During the stop-flapping its wings could be

¹ Marey ("Animal Mechanism," International Scientific Series, fourth edition, 1893, page 200) has shown that in the flight of insects, propelling work is done both on the up-stroke and on the down-stroke. He does not admit that this is the case in birds, for reasons that appear to me to be insufficient. That the bird's wing gives gliding support during the up-stroke appears first to have been taught by Borelli (Marey, *loc. cit.* page 273).

clearly seen to rotate with each stroke. The rotation was such that on the down-stroke the posterior margin of the wing must have been flapped forward about 2 in. or 3 in. more than would have been the case had there been flapping only without rotation. A few minutes later another adjutant was seen to rotate its wings while stop-flapping in the same way. (Fig. 49.)

On a later occasion (November 12th, 1910) I succeeded in seeing similar rotation during stop-flapping in the case of a vulture. This bird was settling on the top of a wall.

It is obvious that the check to forward movement produced by the down-stroke must be increased by this rotation of the wings. The rotation in the opposite direction during the up-stroke must also tend to prevent this stroke having any lifting action. It is probable that this movement is one only visible in extreme cases, as for instance, when the bird has to stop

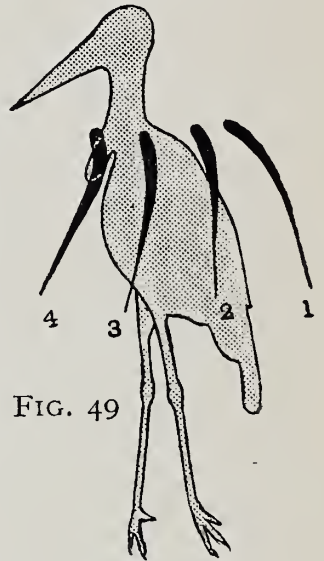


FIG. 49

Rotation of wing of adjutant in stop-flapping. The section of the wing is taken at the junction of middle and inner thirds of the wing. The numbers 1 to 4 show successive positions during the down-stroke. During the up-stroke the same positions are assumed, but in the reverse order.

suddenly in nearly calm air for perching on a wall, etc. It is also probable that rotation occurs in other cases, but to an amount too little to be directly observed.

In the case of the adjutant when settling, lift-flapping may occasionally be observed besides stop-flapping, and the difference between the two kinds of movement can be clearly appreciated. For instance :

August 18th, 1910, at Jharna Nullah. At 5.35.—Several adjutants seen settling. Just before reaching the ground they made one or two flaps with wings fully extended. Then, when their feet had reached the ground, they made two or three flaps with the wing-tips less than fully extended by three or four inches. Both kinds of flaps were in a nearly horizontal direction. Those with the wings extended were ordinary stop-flapping. The other flaps apparently were lift-flapping to ease the strain as the weight of the bird came on to its legs.

In the case of flying-foxes, I have occasionally seen an apparent sudden rotation of the wings through nearly a right angle used as a brake to check speed suddenly when in horizontal flapping flight. This usually occurs to avoid a collision. In horizontal flight the wings may be seen to be flapping up and down (or generally slightly advanced, with appearance of advancing on the down-stroke). In the cases mentioned the wings seem to rotate suddenly through nearly a right angle and to be flapping to and fro. But in two cases I have been able to see that this to and fro flapping occurred with the wings advanced. Probably this advancing of the wings always occurs under these conditions. Flying-foxes may frequently be seen to advance their wings for poising before perching. This poising, as in the case of the kingfisher, occurs with the wings advanced and in to and fro horizontal flaps. The poising only lasts as a rule for a second or two. The hind feet then may be seen to move forward and to clutch the bough. The bat then falls over in any direction and remains hanging by its feet.

A proof that horizontal flapping flight consists of propelling movements with gliding superadded is furnished by the existence of what I propose to term "half-flaps," that is to say flaps in which the range of beat is unusually limited. Crows in Naini Tal when circling occasionally show half-flaps. I have seen vultures make half-flaps after flap-gliding, and before commencing to flex-glide, at a time when the morning development of soarability was taking place. A parrot when settling may make half-flaps with the wings dihedrally-up and advanced. In this case the range of beat of the half-flaps may be between 1 in. and $1\frac{1}{2}$ in. Half-flaps when

settling with the wings somewhat similarly disposed may be shown by flying-foxes. Occasionally kingfishers and adjutant birds may make half-flaps when settling. My notes contain mention of half-flaps made by a butterfly (*Papilio ravana*) that I often observed in Naini Tal gliding for considerable distances without movement of the wings. Half-flaps vary in their amplitude. That is to say there is every intermediate form of movement between gliding and flapping flight.

In poising, maintenance of the bird in the air is due to the beat of the wings alone. In horizontal flight there is also the effect of gliding to prevent loss of height. Hence one would expect that in poising the rate of beat should be quicker than in horizontal flight. In the case of the pied kingfisher when poising the rate of beat is too rapid to count. In some cases it is possible to see that the wings are moving to and fro with great rapidity. In one case in twilight the wings appeared to me as a grey halo surrounding the bird. In horizontal flight the rate of beat is certainly less. The rate of beat of the flying-fox in horizontal flight is usually from .3 to .4 of a second. Occasionally for short distances it may be slower. When poising, as may occur before perching the rate of beat is greatly increased and too rapid to count. As with the kingfisher the amplitude of the beats in poising is also greater than in horizontal flight. The flying-fox, in horizontal flight arches the wing at the bottom of the down-stroke (fig. 50, IX.). On one occasion I was able to see that in poising the arching at the bottom of the stroke was greatly increased so that the wings nearly met in front of the body at the end of the down-stroke (fig. 50, X.)

By the term "beat" I intend to imply an up-stroke plus a down-stroke. The following table gives the rate of beat, during horizontal flight, of different species of birds that have come under my observation :

Swift (<i>Cypselus affinis</i>)	..	..	..	..	.1 sec.
Green parrot (<i>Palæornis torquatus</i>)			..	..	.15 to .25 sec.
Blue jay (<i>Coracias indica</i>)	..	..	..	..	.3 sec.
Crow (<i>Corvus splendens</i>)	..	..	..	..	.3 to .4 sec.
Paddy bird (<i>Ardeola grayi</i>)	..	..	..	..	.4 sec.
Black vulture (<i>Otogyps calvus</i>)	..	..	..	..	.4 sec.
White scavenger vulture (<i>Neophron gingianus</i>)	..				.45 sec.
Adjutant (<i>Leptoptilus dubius</i>)	..	..	..	..	.5 to .45 sec.
Cheel (<i>Milvus govinda</i>)	..	..	..	..	.4 to .45 sec.
Blue heron (<i>Ardea cinerea</i>)	..	..	..	..	.5 sec.

During the whole year, except part of the monsoon season, crows inhabiting the district round Agra collect in the evening and roost on trees on the river bank opposite the Taj. Towards sunset they may be seen flying a few metres above the tree tops following all the chief roads leading into Agra. In the early morning about sunrise they may be seen flying in the opposite direction. Their rate of beat varies according to some unknown conditions. All the crows in sight at one time are, as a rule, flapping at the same rate. On the evening of 17th March, 1911, several crows examined were flapping with .3 of a second beats. On the following evening they were found to be flapping with .38 of a second beats.

The common Black-headed Gull (*Larus ridibundus*), on the other hand, in my somewhat limited experience, has always been found to flap with .4 of a second beats. But under different conditions the amplitude of the beats differs. On some occasions I have observed that in the Arabian Sea and the Red Sea, the beats were of very limited amplitude, so much so that they could

be described as half-beats. In the Mediterranean the beats were of larger amplitude. In London I saw the same species of gull using beats of still larger size. But in each case the rate was the same, namely .4 of a second. So far as visual observation is concerned the speed of the bird through the air appeared to be the same whatever the amplitude of the beat. The Heron is a bird that has no power of soaring flight. Mr. Howard Short tells me he has observed that the amplitude of its wing-beats is greater in unsoarable than in soarable air.

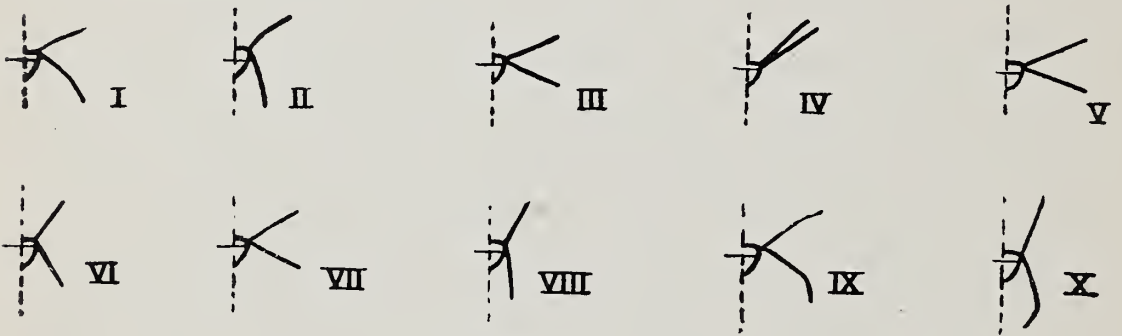


FIG. 50.

Range of beat of wing in flapping flight. In each case the bird is supposed to be seen in end-on view. Half the body only is represented, and one wing at its extreme positions.

- | | |
|--|--|
| I. Paddy bird. | VI. Swift in fast horizontal flight. |
| II. Parrot in fast horizontal flight. | VII. Swift in slow horizontal flight. |
| III. Parrot in slow horizontal flight. | VIII. Dove flying upwards. |
| IV. Parrot making half flaps with wings advanced and dihedrally up, as seen in perching. | IX. Flying-fox in horizontal flight. |
| V. Cheel in horizontal flight. | X. Flying-fox poising before settling. |

It may be noted that in timing birds with a stop-watch it is necessary to count eleven downward flaps to get the time for ten beats. Examples of beats of different range are given in the accompanying fig. 50.

CHAPTER X.

VARIOUS MODES OF DESCENT. GLIDING IN AN ASCENDING CURRENT. LATERAL STABILITY.

It has been shown that a bird when in ordinary gliding flight may steer from side to side by rotating the wing-tip. This procedure checks the speed ahead of the wing whose tip is rotated, which thereupon becomes the inside wing during the turn. As it is probable that this check has to do with a diminution of the angle of incidence (with maintenance of camber),¹ one would not expect this method of steering to be operative when the bird has no speed ahead. Nevertheless when the bird has no speed ahead, and is dropping feet foremost through the air, it has the power of making extremely rapid turns round the dorso-ventral axis, which power it does not seem to possess under ordinary conditions of flight with speed ahead. Facts to be described in the present and the next succeeding chapters will be found to explain these rotations.

If a vulture comes to earth by metacarpal descent speed ahead decreases. In carpal descent the bird is falling feet foremost through the air, and there is almost certainly no increase of speed. But if a vulture descends in a strong wind it may require to maintain or increase its speed ahead. For this purpose it descends by a method that I propose to call "shoulder descent," as the wing is retired by movement at the shoulder-joint. At the moment of change from ease-gliding for instance, to shoulder descent, a small rotation round the trans-

¹ See Chapter XII.

verse axis may be seen to occur, and thus the centre of lifting effort of the wing is brought backwards by the retirement. A couple thereby originates between the "lift" and the "weight." This couple causes rotation round the transverse axis until the centre of lifting effort regains its normal position vertically above the centre of gravity. Flexing also occurs at the elbow-joint. This movement (as shown in Chapter X.) only causes slight diminution of camber. There is little or no flexing at the carpal joint. That is to say, the anterior margin of the wing-tip remains in its normal position at right angles to the line of flight, and consequently air continues to impinge on the under surface of the wing-tip feathers, and steering from side to side takes place by wing-tip rotation.

Shoulder descent is the mode of descent usually employed by the smaller birds when coming down from a height. In this form of descent the wings may be dihedrally-down (parrots, mynas), leading to a decrease in the angle of incidence and increase of speed, or flat (vultures), or rarely dihedrally-up. I have seen descent with wings retired and dihedrally-up in a pigeon. This was probably a mode of decreasing speed. I have also seen a large swallow-tail butterfly (*Papilio ravana*) glide downwards at a small angle with the horizon with front wings retired and dihedrally-up. If this butterfly wishes to descend more rapidly, it places its wings at a dihedral angle approaching 45° , and then drops feet foremost through the air.¹ It checks its fall by decreasing the dihedral angle.

When near the ground, scavengers, crows, and smaller birds frequently check speed by increasing the

¹ I have on one occasion seen a swift drop feet foremost through the air in this way, but only for a short distance.

angle of incidence above the normal. To do this the bird advances its wings. This causes rotation round the transverse axis until the "lift" is again vertically above the "weight," thereby increasing the angle of incidence. The bird is not appreciably deflected from its course by this procedure. It continues to travel ahead but with diminishing speed. A crow having thus checked its speed to some extent may bring itself to a full stop by a further advancing of its wings, with further consequent rotation round the transverse axis. It then drops vertically downwards through a distance of 1ft. to 2ft. on to its perch. This clumsy mode of descent is in strong contrast to the graceful movement of the vulture which always glides to its perch without any sudden change of course.

From its similarity to stop-flapping, this mode of checking speed may conveniently be described as "stop descent."

I will now quote cases of carpal descent in which as will be seen sudden rotations round the dorso-ventral axis not infrequently occur :

June 15th, 1910, at Naini Tal Lake. At 4 p.m.—A cheel noticed in a strong wind descending with legs hanging down, and the plane of its wings horizontal. It was facing the wind, and descending vertically. The wings were flexed to a greater extent than occurs in flex-gliding. The tail was furred and directed upwards. Twice at least a forward extension of the alulæ was observed. Towards the end of the descent (when within 3ft. of the surface of the lake, and near some overhanging trees) the cheel was seen to turn suddenly in the horizontal plane through an angle of about 90° —that is to say, the bird rotated round its dorso-ventral axis without canting. After an appreciable pause (a small fraction of a second) it turned with equal suddenness back to its original direction.

June 22nd, 1910, at Ballia Ravine. At 4.37 p.m.—A brown vulture gliding overhead flexed its wings more than usual. It began to descend vertically with legs hanging down, and losing speed ahead. Then it expanded its wings, and, for an appreciable interval, appeared to remain motionless in the air. Then it gathered speed ahead. Then, flexing its wings with secondaries taut (*i.e.*, metacarpal descent), it descended in the usual spiral, steering by dip movements. When near its perch, drop

turns with small rotations round the dorso-ventral axis were noticed. When still nearer its perch the alulæ were seen to be extended.

June 30th, 1910, at Ballia Ravine. At 3.50.—A vulture seen descending from a great height vertically. Its wings were strongly flexed and flat. They were in the horizontal plane—that is to say, the bird was dropping through the air feet foremost. The alulæ were extended and in motion. Probably, while so descending, the vulture was in a strong wind. After descending for some distance in this way, it extended its wings, not fully, but to the usual position (for metacarpal descent); then it lowered its legs, and continued its descent by the ordinary method.

December 18th, 1910, on Tundla Road beyond Jharna Nullah. At 11.30.—A strong east wind. An eagle seen in carpal descent from a height. It descended nearly vertically, and perched on a tree. It began to lower its legs when about 20 metres above its perch. The alulæ were clearly seen to be strongly advanced during the whole of the descent, but they were not in motion. The tail was expanded. The bird showed slight instability round the longitudinal axis after the legs had been dropped.

The question arises as to what is the object of advancing the alulæ during carpal descent? The last case described suggests that the purpose of the movement is to bring more supporting area in front of the level of the centre of gravity without increase of span. There can be no doubt that the advancing of the alulæ must alter to a slight degree the position of the centre of lifting effort of the wings as a whole, and so may play a part in maintaining equilibrium round the transverse axis.

It will be obvious from the above description that it may be difficult in some cases to distinguish between carpal and shoulder descent by observation. For instance :

June 27th, 1911, at Ballia Ravine. At 9.53.—A vulture seen easing. The white feathers of the underside of the wing appeared yellowish-green. It changed to metacarpal descent, and appeared white. Then, giving a dorsal view, it changed to the carpal descent wing disposition. The centrally-placed secondaries could then be seen to be in slight flickering up-and-down movement. The range of movement may have been half an inch. This may be regarded as a proof that at this moment the angle of incidence was zero.

There is room for doubt as to what happened in this case. My recollection is definitely that at the time when the secondaries were flickering the bird had ample

speed ahead, and was not noticeably dropping feet foremost. It is possible that after the metacarpal descent there was a short period of shoulder descent, in which the angle of incidence is maintained, and that this was followed by carpal descent, with no angle of incidence, and in which therefore the feathers were free to move up and down like a flag shaking in the wind. Other possibilities may be suggested. It is not a point on which a definite opinion can be formed.

The following is another similar observation :

August 5th, 1911, at Jharna Nullah. At 5.50.—A vulture flex-gliding downwards, with speed ahead, in a strong wind, with legs dropped. Shaking of some of its feathers was seen. I could not recognise which, as the wind was moving my binocular.

In the first-quoted case of carpal descent the bird showed a sudden turn round the dorso-ventral axis. This as usual in carpal descent occurred while the bird was in a strong wind. Similar turns while the bird is falling through the air feet foremost may be seen in absence of wind. For instance :

June 10th, 1910, at Ballia Ravine. At 4.0 p.m.—Some cheels ease-gliding in a limited and sheltered place between rocks and trees were seen making flat turns—that is to say, turns without canting. The birds were gliding downwards with wings strongly flexed. They seemed to turn on their dorso-ventral axes instantaneously. Cheel after cheel was seen making this turn in the same part of the ravine, or rather in a cleft in the rock. It was impossible to see the movement by which the rotation was brought about. The amount of turn must have been nearly 180° . The cheels made these turns in a sheltered place, but a light wind was blowing up the main ravine.

In the following paragraphs I propose to describe the movements of cheels when gliding in an ascending current of air. It will be seen to be possible to make a suggestion as to the nature of the adjustment by which sudden rotations are produced.

In previous chapters I have mentioned the behaviour of cheels when gliding in an ascending current over

the battlements of the Agra Fort. I now propose to describe this form of flight more minutely.

Before describing what I have observed, it will be convenient to describe briefly what one might expect to observe.

Let us consider the case of a bird gliding horizontally in unsoarable air. There is a small angle of incidence. Consequently the centre of pressure of the air on the wing does not coincide with the centre of area. As is well known, the centre of pressure is somewhere between this point and the anterior margin. The smaller the angle of incidence the nearer it is to the anterior margin. In this form of flight the bird keeps its wings "straight," neither advanced nor retired. When the wings are in this position the centre of lifting effort, or briefly "lift," is at a point vertically above the centre of gravity.

Now let us imagine the case of a bird supported on a vertically ascending current of air. Let us suppose further that it is not gliding ahead. We may imagine the wings to be spread out horizontally. The air exerts pressure on the underside of the wing at right angles to their surface. That is to say, the angle of incidence is 90° . Therefore the centre of pressure must coincide with the centre of area. If the wings were in the "straight" position, as in the first case, the centre of pressure would be at a point some way behind the centre of gravity. Therefore there would be a couple between the "lift" and the "weight" which would rotate the bird downwards round its transverse axis. So if the bird wishes to remain horizontal it must advance its wings.

Now let us consider what the bird must do if it wishes to take advantage of the ascending current to

produce speed ahead. It would flex the wings at the carpal-joint. Thereby as already shown the secondaries would be relaxed, and the free or hind ends of the secondary quills would be pressed upwards by the air. The effect is shown in fig. 51 at B. The ascending current would be deflected as shown by the arrows. The resulting force of reaction would then drive the bird ahead.

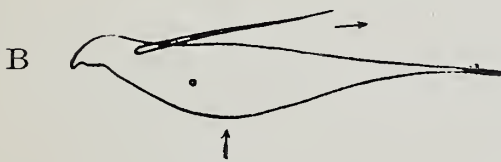


FIG. 51.

We may now consider the actual facts of observation. The above-described disposition of the wings is seen when the bird wishes to make speed ahead. But usually the bird wishes to remain in the ascending

Cheel gliding in an ascending current of air at moment of turn. A shows disposition of the inside wing. B shows disposition of central portion of outside wing. The reflection of the air current by this part of the wing is indicated by arrows. The dot in each figure shows the position of the centre of gravity.

current more or less at one spot, or it glides along the battlements, heading in a direction of perhaps 45° or more from the wind direction. Further the current does not ascend vertically but rises at varying angles with the horizon. Hence the wings are usually held somewhat advanced with the wing-tips slightly retired. That is to say, it is probable that there is a decrease of camber as compared with the disposition for circling, and also a decrease of the angle made by the wing with the horizon. But the exact disposition of the wings varies rapidly with the varying currents, and is difficult to see.

Should the wind freshen relaxation of the secondaries at once occurs in order to increase speed ahead and

thereby keep the bird in its position over the battlements. In the following instances the bird at once took advantage of the ascending current to aid it in travelling up-wind :

August 10th, 1911. At 6.33.—In a gust of wind a cheel leelooping and flap-gliding up-wind. As it came into the ascending current reflected upwards from the house, it retired the wing-tips and relaxed secondaries. As soon as it got beyond the influence of the ascending current, it tightened its secondaries, and glided with wings slightly arched, with loss of height, and settled as the gust of wind died away.

August 27th, 1911. At 6.57.—Wind moving small branches. A cheel flap-gliding up-wind. It glided over the house at a height of about 4 metres above it. When it reached the ascending current reflected by the windward side of the house, it relaxed its secondaries. As soon as it was beyond this current, it flapped. In the next period of gliding, it had secondaries taut and wings slightly arched.

7.25.—A cheel gliding up-wind during a lull passed over the house showing no relaxation of secondaries—that is to say, relaxation of secondaries only occurred when there was an ascending current.

The following observation gives a clue to the probable method employed for steering when in an ascending current :

April 15th, 1911, at Jharna Nullah. At 5.50.—Some cheels wind-facing in an upward current of air on the windward side of a shed. In several cases, when turning (in the horizontal plane) opposite the end of the shed, they advanced the outside wing, flexing it at the same time. The advancing must have been as much as an inch at the carpal joint. The wing-tip was retired through, perhaps, two or three inches. The turn was gradual, but the advancing was a sudden movement. The upward current was only just strong enough to support the cheels at about 2 metres height above the shed. It was not strong enough to support scavenger vultures. Some of these were near in flapping flight, and others were settled.

It is necessary to consider in detail what happened in the above case. Fig. 52 shows diagrammatically the movements of the bird. Fig. 53 shows the outline of the outside wing before and after the flexing. It is probable that the flexing of the outside wing caused it to assume the slow or medium flex-gliding position. Fig. 51 shows diagrammatically the probable sections taken at about the central parts of the two wings during

the movement in question. For the sake of clearness, the probable amount of difference in the disposition of the two wings has been exaggerated in the drawing.

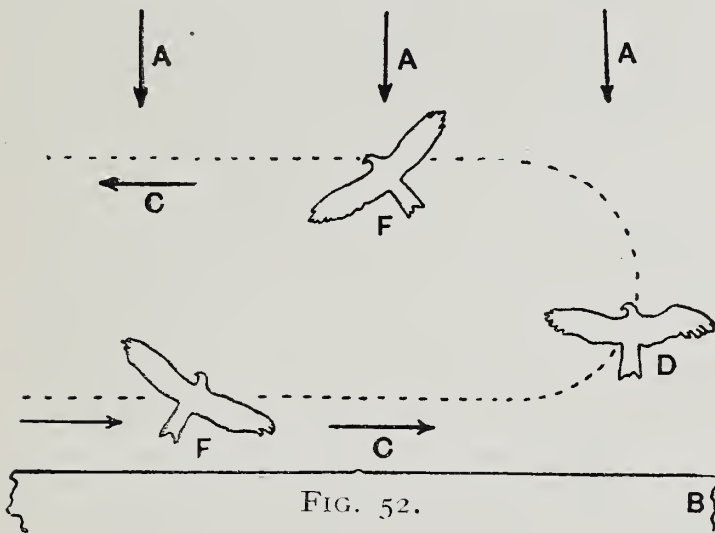


FIG. 52.

The inside wing is shown at A. It is cambered but not so much so as in circling. The outside wing is represented at B. Owing to the flexing the secondaries are relaxed, so that the

Diagram showing a bird's-eye view of cheel turning in an ascending current of air. A A A, wind direction. The wind, on striking the wall of the shed B is deflected upwards. C C, direction of gliding flight of the cheel. At D the outside wing is shown flexed and advanced. For the sake of clearness the cheel is represented as making a gain to windward during the turn. This did not occur. The cheel turned on its dorso-ventral axis (or nearly so), and turned approximately along the track on which it came.

posterior margin of the inner part of the wing forms a curved line with the convexity upwards. Hence, though the greater part of the outside wing is flat or slightly cambered, the secondaries of the central part of the wing are relaxed. That is

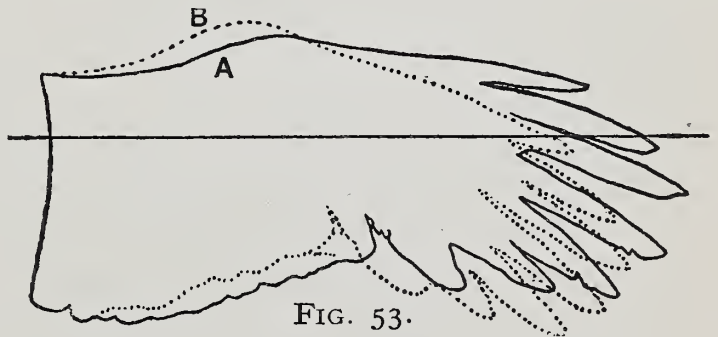


FIG. 53.

Outlines of wing of a cheel. At A when slow flex-gliding. At B when medium speed flex-gliding. The horizontal line shows the level of the centre of gravity.

to say, their free ends are directed upwards. Hence the ascending current of air striking this part of the wing is reflected, as shown by the arrows, and in being reflected tends to drive ahead the wing in question.

So much for the facts. My supposition as to what actually occurred is this : The cheel, having speed ahead, commenced its turn by a depression of the inside wing or wing-tip which was not observed. The speed ahead having been abolished by this turn in the horizontal plane, and the cheel being supported in the ascending current of air, it relaxed the secondaries of the outside wing to obtain an additional steering effect. Probably this relaxation of the outside wing (which was only visible for a fraction of a second) was followed by slight extension of the same wing and then relaxation of the inside wing. Thus both wings would acquire the same disposition. This adjustment would tend to check the rotation and to produce speed ahead.

Obviously this relaxation of the secondaries of the two wings to different extents may be the means employed of producing rapid turns round the dorso-ventral axis, such as occur when the bird is falling feet foremost through the air. I have seen a cheel make such a turn, amounting to 360° , when in a sheltered place and having no speed ahead. Obviously such a turn could not have been caused, under the circumstances, by wing-tip rotation. It could have been caused by unequal relaxation of the secondaries of the two wings.

Hence it appears that birds have two methods of steering in the horizontal plane, one for use when there is speed ahead, the other suitable for use when there is speed feet foremost but no speed ahead. One method acts by checking speed of the inside wing, the other method acts by giving speed to the outside wing.

Certain somewhat obscure movements of the outside wing-tip in circling have been described elsewhere. These movements obviously resemble a steering adjust-

ment of the second kind. These movements most commonly occur at the end of the windward side of the track, and when speed is about to increase for the downwind side, *i.e.*, at this point of the track, the outside wing of the circling bird behaves as if it were in an ascending current of air.

There is a certain similarity between slow flex-gliding and gliding in an ascending current which it will be of interest to consider. It is a matter of easy and certain observation that in fast flex-gliding the secondaries are so far relaxed that the camber is abolished and the angle of incidence is negative. Suppose a line is drawn horizontally backwards from the front edge of the wing, then the free or hinder edge of the wing does not lie below it as in ordinary gliding. It lies above it. That is to say, the plane of the wing makes an angle with this horizontal line. The angle may be about 20° .

Observation makes it probable that in slow flex-gliding there is a small negative angle of incidence of this nature. Also the camber is nearly, if not quite, abolished. The wings are less advanced than in fast flex-gliding. Therefore in slow flex-gliding, and in no other form of soaring flight, the wings assume a disposition that appears identical with that assumed for gliding at speed in an ascending current.

This similarity between slow flex-gliding and gliding in an ascending current makes it probable that steering in flex-gliding flight is not arrived at by dip movements, but by varying the amount of relaxation of the secondaries of the two wings.

It is not always easy to distinguish between slow flex-gliding and ease-gliding. The two forms of flight shade off into one another by imperceptible gradations,

especially in the case of cheels. In slow flex-gliding the angle of incidence of the secondary quills is negative, but the angle of incidence of the wing-tip is either zero or positive. Hence cases observed of wing-tip depression of the inside wing for steering in slow flex-gliding do not invalidate the view that steering in fast flex-gliding is caused by relaxation of secondaries of the outside wing. The following observations may be quoted :

12th November, 1910, at Jharna Nullah. At 3.9.—Wind north-west, moving branches. Slight sunshine.

3.11.—Sun in. Vulture in slow flex-gliding seen to turn to go up-wind by retiring outside wing-tip. Vultures at a height fast flex-gliding. Vultures coming down seen to steer by dips of inside wing.

10th January, 1911, at Jharna Nullah. Strong steady west wind, moving branches. Sun shining, but thin cirrus over sky. Vultures circling with wings not advanced, and a few adjutants up.

11.0.—A vulture slow flex-gliding showed the digital gap three times. The last of these was seen to produce a steering effect. It then came down by metacarpal descent. While so doing it appeared of a lighter yellow colour, and when low down appeared nearly white. (These movements were half-dips of the inside wing.)

18th May, 1911. At 9.0.—Cheel slow flex-gliding in stormy soarable wind steered by tightening inside wing secondaries.

15th September, 1911. At 2.34.—A cheel fast flex-gliding. Increase of flexing of outside wing seen for steering. Wind west, moving leaves.

20th September, 1911. At 3.55.—A vulture flex-gliding 200 metres up. It steered twice, but no steering movement was visible. It then changed to ease-gliding, and steered by means of a dip movement of inside wing.

5th November, 1911. At 10.20.—Wind apparently south. Leaves still. Cheels in steady flight.

10.35.—A vulture slow flex-gliding changed to circling. At moment of change it steered through nearly a right angle, and the secondaries of the outside wing appeared to lift.

9th November, 1911. At 9.10.—Cheels flex-gliding were in steady flight. A cheel flex-gliding showed a depression of the inside wing for steering.

An important part of the control of an aeroplane is the means adopted for ensuring lateral stability. The question arises as to the nature of the method employed by birds for subserving this important adjunct to their powers of flight. I have seen a cheel gliding through the open doorway of a racket court. The doorway was

too narrow for the expanded wings of the bird. As it reached the door, it smoothly and evenly canted itself over, glided through in this canted position, and then when on the other side, presumably returned with equal smoothness to a level keel. I believe it is the perfection of the method employed by birds for thus canting to one side or the other that has prevented my discovering its nature with certainty by direct observation. Some facts to be described in the following paragraphs will, however, enable us to draw an inference as to the nature of the adjustment.

I have already proved that lateral stability is not maintained by rotation of the wing-tips in opposite directions. It is conceivable that lateral stability might be maintained by rotation of the wings themselves in opposite directions. But it is not likely that birds would employ an adjustment in which both wings would be so placed as to tend to check speed ahead, and in which the lifting efficiency of both wings would be diminished. Further such a suggestion is not supported by any facts of observation. It is possible to observe wing rotation. For instance I once saw a cheel for a fraction of a second rapidly rotate its wings to and fro to a very small extent round **their** long axes. This happened while the bird was gliding and about to perch. Probably the movement was anticipatory to stop-flapping, in which as elsewhere proved, rotation of the wings occurs or can occur. Also the movement that I have described as "wing depression" has been shown to be due to wing rotation lasting slightly longer than in this instance.

That cheels can catch food thrown to them while they are gliding in the air, and that they always catch

the food with their feet, never with their beaks, are well-known facts. The details of the extremely rapid movements by which they accomplish this feat are very difficult to observe. The fact that one can hardly help feeling amusement or astonishment at the agility of the bird adds to the difficulty of making the observation. It is my experience that the power of observation of highly transitory movements is greatly diminished if the consciousness is occupied by any feeling, whether of surprise, interest, or pleasure.

On one occasion I was able to follow the movements of cheels catching food in the air. I was throwing pieces of bread to cheels from the terrace outside my house. This terrace has a height of about 15ft. from the ground. At first the cheels were gliding in front of me and had to make a sudden turn and a dive in order to catch the bread. Then the cheels having learnt what I was doing, kept gliding in the air behind me, so that on swooping they travelled in the same direction as the piece of bread, and could catch it the more easily. An example of catching a piece of bread after a difficult turn is the following :

October 13th, 1910. At 4.15.—A cheel was gliding past in front of me about 5ft. above my level as I threw a piece of bread. When the cheel had reached a point about 10ft. to the left of the position where the piece of bread was falling, it rotated round its transverse axis through about 90° . At the end of this rotation the longitudinal axis of the bird was vertical instead of being horizontal—that is to say, the beak pointed vertically upwards and the tail downwards. Then the cheel rotated through 180° round its dorso-ventral axis—that is to say, after making this second rotation, its beak pointed downwards and its tail upwards. This movement was quicker than the transverse axis rotation. I could see that the wings were flexed during this second rotation. While it was making these rotations a small feather dropped off. The cheel then swooped downwards, and caught the falling piece of bread at a time when the latter had reached a point about 2ft. from the ground. While swooping, the wings were flexed, and there was no flapping. As usual, the cheel caught the bread in its claws, not its beak. The rotation round

the transverse axis was presumably due to advancing of the wings, as observed in other cases. At the moment of catching the bread, the cheel began gliding upwards (in a curve of long radius). As observed in other cases, this gradual change of course must have been due to placing the wings in the dihedrally-up position. The bird glided upwards, and reached about its original height. Then, as usually occurs, the claws were brought forward and the head bent down and backwards, as the bird ate the bread without interruption of its gliding flight. (See fig. 54.)

In the above account I have described two methods of producing rotation round the transverse axis. The first by advancing the wings causes a sudden rotation and is associated with loss of speed ahead,

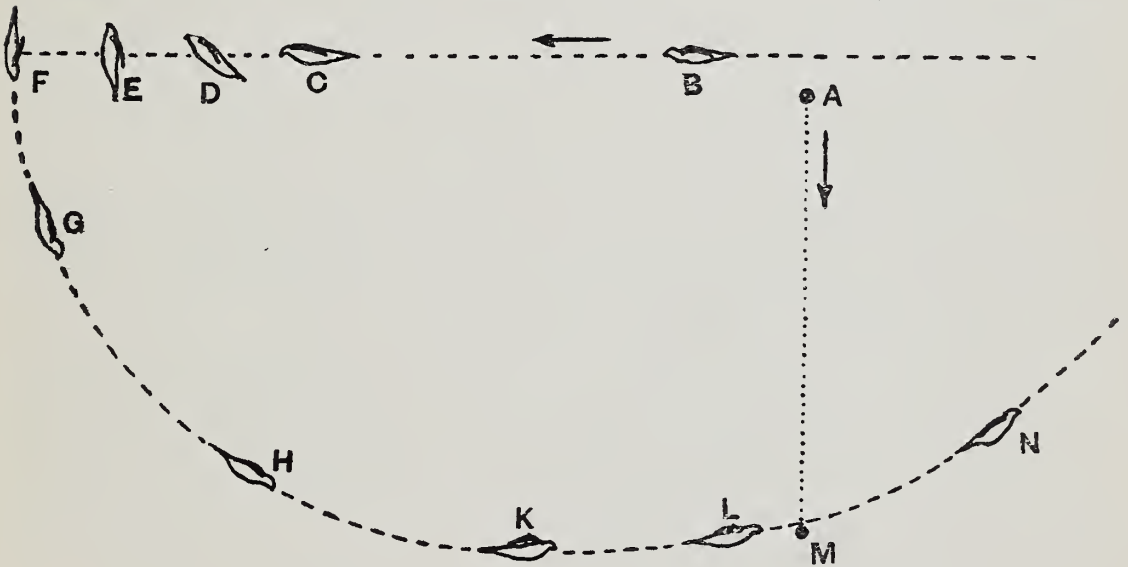


FIG. 54.

Movements of a cheel when catching food thrown to it in the air. A, a piece of bread falling while a cheel is gliding past at B. At C the cheel advances its wings. In consequence the bird rotates through 90° round its transverse axis, as shown at D and E. The cheel then rotated 180° round its dorso-ventral axis, as shown at F. The wings are now flexed, and secondaries relaxed. The bird then swoops down, as shown at G and H, gradually extending its wings, and increasing their camber. At K and L the wings are shown in the dihedrally-up position. This adjustment causes gradual rotation round the transverse axis. The bird consequently glides upwards, catching the bread M in its claws as it passes. The cheel carried out these manœuvres while the bread was falling from A to M, a distance of about 15ft.

speed ahead being changed into speed feet foremost. This feet-foremost speed obviously was the source of the energy used for rotation round the dorso-ventral axis, and also was a part source of the energy required

for the swoop, whose speed was greater than could be accounted for by gravity alone. The second method of producing rotation round the transverse axis was by placing the wings in a dihedrally-up position. This method causes a more gradual turn, and is used in cases in which speed ahead is maintained.

On one occasion I was with a friend at Jharna Nullah, and within a few minutes we saw two cases in which a cheel dropped a piece of meat and caught it before it reached the ground. In each case the cheel was being chased by other birds. Apparently to drop a piece of food and again catch it in this way is a method used by cheels to baffle pursuit.

Cheels when swooping steeply downwards sometimes show to and fro rotations of large range round the longitudinal axis. For instance :

October 17th, 1910. At 3.30.—When feeding my captive adjutant, I threw some pieces of meat into the air. Some cheels swooping for these showed rapid to-and-fro oscillations round the longitudinal axis. Two of them, after checking speed ahead by advancing wings, showed rapid rotation round the dorso-ventral axis. During this rotation the wings were only slightly flexed.

According to my recollection of this incident, the adjutant was threatening the cheels by snapping its beak at them. In certain cases therefore the cheels had occasion to check speed suddenly by advancing their wings. I recollect one of these cheels swooping towards a piece of meat and oscillating round its longitudinal axis. As the meat had reached the ground, and as the adjutant was walking up to it the cheel changed its mind, rotated round its transverse axis to check speed, and glided away.

By the term "oscillation round the longitudinal axis," I mean that the bird became strongly canted over to one side, returned to a level keel, and then

became canted in the other direction. There can be no doubt that this canting to one side or the other was not due to atmospheric irregularities. It must have been due to some more or less voluntary adjustment. The question arises what was its nature?

In the above case, longitudinal axis oscillation preceded the advancing of both wings. So far as I am aware similar longitudinal axis oscillation only occurs if both wings are about to be advanced. For instance, cheels, when playing together in the air often swoop downwards for short distances and in so doing show the oscillation in question. Several times I have noticed such oscillations in the case of cheels swooping downwards in order to perch. In these cases the wings were placed dihedrally-upwards to change the direction of the swoop. This was immediately followed by advancing to check speed. In each of these cases it seemed to me that the wing that became uppermost during the canting had been advanced. But this was merely an impression, not a definite observation.

On the other hand, so far as my experience goes, if the swoop is not going to be followed by advancing the wings no oscillation round the longitudinal axis occurs. For instance, if a cheel is swooping downwards to snatch a piece of food from the ground it does not check its course by advancing the wings but changes the direction of its swoop by placing the wings in a dihedrally-up position. When thus swooping downwards there is no appearance of lateral instability. Further cheels and eagles sometimes swoop downwards and glide up again in one long curve without checking speed. This change of course is produced by varying the dihedral angle of the wings, and again no sign of lateral instability can be observed.

Thus it appears that longitudinal axis oscillations only occur if the bird is about to advance both wings. It is probable therefore that the oscillation is due to some "anticipatory movement," in this case a movement anticipatory to advancing both wings. Obviously the movement cannot have been an advancing of both wings. It is doubtful whether increased flexing could have produced the effect observed unless it was of such an extent as to be noticeable. The range of longitudinal axis oscillation observed may have been as much as 60° or 80° . Further, flexing would not have been a movement of an anticipatory nature.

Let us consider whether advancing of the two wings alternately could have produced the effect observed.

I have already shown that an advancing of both wings would cause rotation upwards round the transverse axis. If both wings are advanced their front edges and the head end of the bird are raised. At the same time the tail drops. Supposing only one wing is advanced then the front edge of this wing will be raised. The front edge of the other wing is not raised. In other words the bird becomes canted.

Obviously if canting can be produced by advancing one wing canting in the same direction will also be produced by retiring the other wing. Possibly the following observation is an example of such an adjustment:

November 16th, 1910, at Jharna Nullah. At 10.40.—A brown vulture flapping a few feet over my head showed a retirement of the inside wing. It was flying on a curved course.

I suggest that the movement observed was an adjustment for canting. Possibly the movement was accompanied by increased flexing, that is to say, by an adjustment for steering.

It is regrettable that so important a conclusion is based merely on inference and not on sufficient or certain observation. My suggestion is that a bird in gliding flight when steering to one side rotates one wing or wing-tip, while at the same time the wing is retired, the rotation produces steering, and the retirement produces the requisite amount of canting. The implication is that lateral stability is, in part at least, maintained by advancing or retiring of one wing. This suggested method is obviously of great simplicity and not one involving any large decrease in wing efficiency.¹

In the following instances I have, as I think, succeeded in seeing canting produced by retirement of the inside wing :

6th November, 1911. At 8.55.—A dove gliding downwards in my direction showed a sudden retirement of inside wing with steering effect and canting.

22nd October, 1911, at Jharna Nullah. Wind west, moving small branches.

10.40.—An adjutant seen descending and facing me, with legs hanging down. It became strongly canted. At this moment the lower wing appeared to be retired to such an extent that the wing-tip was two or three inches aft of its normal position. At the same time this wing-tip was rotated downwards.

25th June, 1913. Top floor of Grand Hotel, Calcutta.—A crow gliding with loss of height seen suddenly to retire inside wing. The movement was sudden, like a jolt, and somewhat trembling. The range of movement of the wing-tip appeared to be an inch. It made a sharp turn with canting.

It might be objected that the steering movements already described are in themselves sufficient to produce canting, and that no further adjustment is required. For instance, if in soarable air a bird rotates a wing or wing-tip the angle of incidence is altered ; the air ceases to drive the wing ahead. The supporting power of the

¹ An attempt to imitate the method of lateral control employed by birds appears to have been attempted in the De Marçay monoplane. In this machine the wings can be advanced or retired for a short distance for lateral control. This method is employed instead of warping. I have no evidence as to how far this method is a practical success. (See *Flight* Vol. V., pages 437 and 485, of 19th April and 3rd May, 1913.) My discovery of the method of control employed by birds was first published in *Flight* on the 25th November, 1911, Vol. III., page 1015.

wing therefore diminishes. Hence the bird may become canted. Without pausing to discuss how far such an explanation can apply to unsoarable air it can definitely be asserted that it will not meet the case of the cheel.

The cheel shows far greater agility when in the air than other birds with which I am acquainted.

On one or two occasions I have seen a cheel gliding for a fraction of a second upside down. Several times I have seen a cheel gliding in the air catch another cheel by the claws. The two birds remained hanging on to each other by the claws for an appreciable time. The under bird was upside down. In each of these cases it was impossible to see how the cheel reached its unusual position, but that sudden rotations round the longitudinal axis occurred will be shown in Chapter XIX.

In vultures slight steering movements can occur without canting. In cheels considerable canting can occur without steering.

The dove (*Turtur cambayensis*) frequently flaps nearly vertically upwards to a height of 5 to 10 metres above the tree tops. Then it glides downwards in long sweeping curves with wings dihedrally-down and tail expanded. Twice I have seen this dove advance the inside wing during or after a turn as if with the object of preventing canting. This dove habitually turns in the horizontal plane in a curve of long radius with scarcely any canting.

I may here describe what I propose to term the "emergency adjustment." If a vulture is startled by suddenly discovering the approach of another bird, or by a rifle bullet whizzing past it, it suddenly flexes its wings and lowers its legs. A relaxation of the secondary quills may also be seen. That is to say the vulture

changes its gliding flight to "carpal descent." By lowering the position of the centre of gravity, and by decreasing the supporting area of the wings, it thus turns itself into a sort of parachute. But, as already explained, the disposition of the secondary quills in this form of descent is such as to permit speed ahead rather than the irregular swaying of an actual parachute. As soon as the danger is past the bird expands its wings and resumes its flight. Twice, or perhaps three times, I have as I think, seen this adjustment used for dealing with an atmospheric irregularity. I have also seen the adjustment used by crows and cheels besides vultures. Presumably if the bird was canted and the upper wing was struck by a gust of wind the flexing would affect the upper wing first in order to hasten the return to a level keel. In the case of flying-foxes flying broadside-on to a stormy wind behind trees, I have seen occasional sudden flexing of the wings as if as an emergency adjustment of this nature.

CHAPTER XI.

THE POSITION OF THE CENTRE OF GRAVITY. FACTORS AFFECTING THE ANGLE OF INCIDENCE.

It would be premature to speculate as to the nature of the force of soarability without first bringing forward evidence as to the direction in which this unknown force is operative and also evidence as to its intensity. I propose in the present chapter to adduce evidence bearing on these points. It will be found that the facts of the case as to the position of the centre of gravity in different kinds of flight have an important bearing on the question as to whether soaring flight can be explained by vertically ascending currents caused by the heat of the sun. Evidence as to a possible relation between such currents and soarability will be brought forward in Chapter XV.

The following diagram (fig. 55) represents a side view of a vulture when gliding in a straight line in unsoarable air.

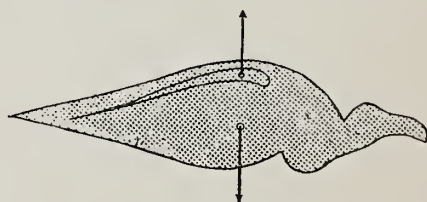


FIG. 55.

Section of a vulture gliding in unsoarable air.

It will be seen that the position of the centre of effort of the wings is vertically above the centre of gravity. Supposing the vulture advances its wings (fig. 56), then a couple is produced tending to rotate the bird upwards round its transverse axis. Such rotation, as we have seen, actually occurs. The bird rotates until it assumes the position shown in fig. 57.

Thus the centre of lifting effort re-acquires its position vertically above the centre of gravity. Con-

versely if the bird retires its wings a couple originates that rotates the bird in the opposite direction, thus (fig. 58), and again the centre of effort is vertically above the centre of gravity.

Therefore, so long as the bird is gliding in a straight line in unsoarable air the centre of effort of the wings is vertically above the centre of gravity. If

the centre of effort is displaced rotation round the transverse axis at once occurs until the centre of effort is again vertically above the centre of gravity. We have already seen that when a bird is gliding in an ascending current the same law holds. Under these conditions the centre of effort is

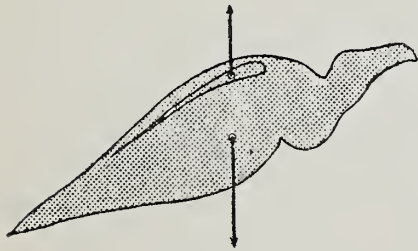


FIG. 57.

Effect of advancing wings : near the centre of area of the wing, and in order to remain

gliding horizontally the bird advances its wings until the lift is vertically above the weight.

Does the same relation hold when the bird is subjected to a propelling force as in flapping or when soaring ?

Let us first consider the case of flapping flight. We have already seen that if the bird while flapping changes its wings from the "straight" to the "retired" position it rotates round its transverse axis and the direction of its flight is in a downward direction. Conversely if as in stop-flapping the bird advances its wings it rotates upwards round the transverse axis. These facts

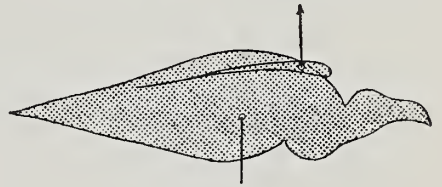


FIG. 56.

Effect of advancing wings : First position.

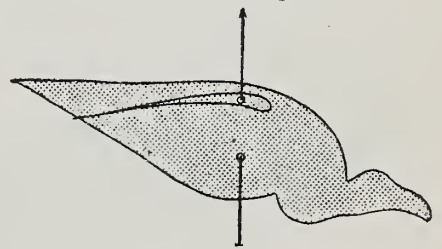


FIG. 58.

Effect of retiring wings.

suggest that the law holds good. But if this is the case why is it that the wings are advanced in slow horizontal flight, and why does the amount of advancing diminish as speed increases?

Supposing a bird is gliding horizontally in calm air, and someone momentarily catches hold of its tail so

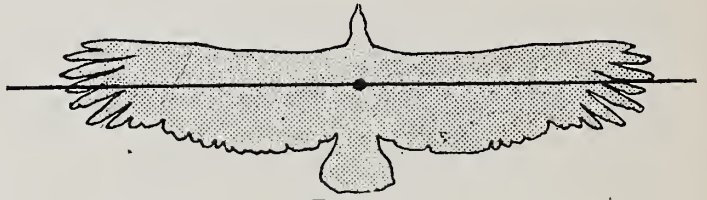


FIG. 59.

Outline of a vulture circling in air not fully soarable, or circling in fully soarable air without effort to gain height.

as to check speed ahead. Supposing in consequence the bird were to flap its wings up and down in order to regain speed ahead. Then at first, as the air strikes the surface of the wing nearly at a right angle, the "lift" is at a point near the centre of area. Hence the bird has to advance its wings in order to bring the "lift" over the "weight." Hence the wings can be seen to be advanced in slow flapping flight. But as speed ahead increases the angle of incidence diminishes. Consequently the "lift" approaches the anterior margin of the wing. Therefore the wing has to be retired in

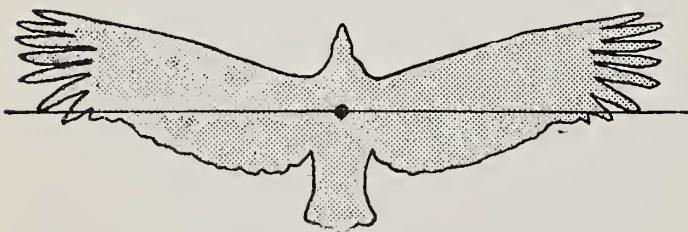


FIG. 60.

Outline of a vulture circling in fully soarable air and with effort to gain height.

order to keep the "lift" vertically over the "weight." Hence in fast horizontal flapping flight no advancing of the wings is to be observed.

This description is only approximately correct. The force of flapping has to neutralise not only the weight, but also the resistance to forward movement through the air. If a bird is in movement in the air

it may be regarded as being acted on by four chief forces, namely "lift," "weight," "pull," and "drag." In flapping flight the force exerted by the wings may

be regarded as compounded of "lift" and "pull."

Of these two forces the "lift" acts vertically and the "pull" horizon

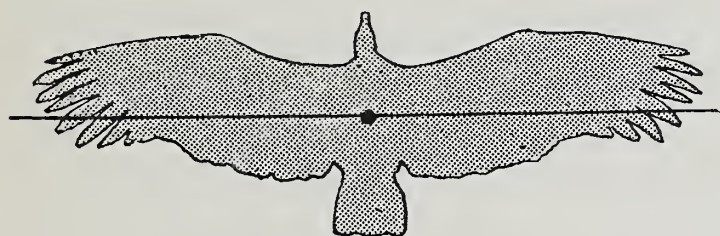


FIG. 61.

Outline of a vulture slow flex-gliding
(8 metres per second).

tally. Their resultant may be called the "total pull." It is a force acting upwards and forwards. It balances a force compounded of the "weight" and the "drag." This force, which acts downwards and backwards, may be called the "total drag."

If a bird is taking energy from the air in soaring flight it is being subjected to a propelling force.

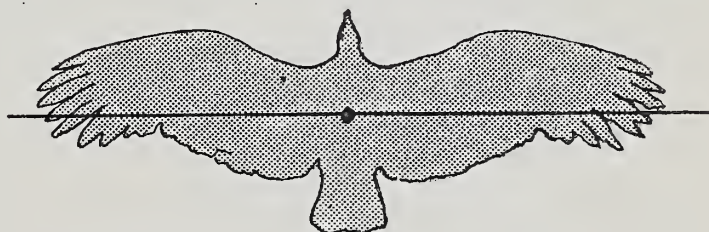


FIG. 62.

Outline of a vulture flex-gliding at medium
speed (12 metres per second).

Therefore the forces acting on it may be regarded as resulting in a "total pull" and a "total drag." By examining the position of the wings in different kinds

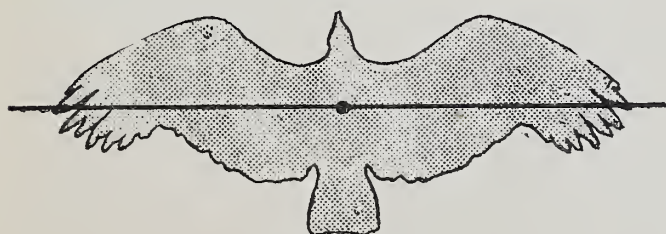


FIG. 63.

Outline of a vulture fast flex-gliding
(22 metres per second).

of soaring flight we shall be able to arrive at some conclusions as to the direction from which the unknown force of soarability acts.

Figs. 59 to 63 show outlines of a vulture when circling and when flex-gliding at different speeds. It

will be seen that as the speed of flex-gliding increases the larger is the proportion of wing area in front of the position of the centre of gravity.

If a vulture is circling in fully soarable air with effort to gain height its wings besides being advanced are placed in a dihedrally-up position, as in fig. 64.

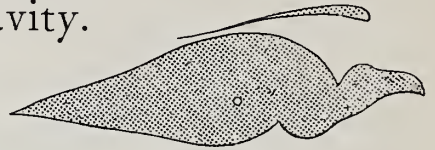


FIG. 64.

Section of a vulture circling in fully soarable air.

A further reference to this employment of the dihedrally-up position will be made when I come to discuss the functions of the wing-tips.

A section of a vulture when slow flex-gliding is shown in fig. 65.

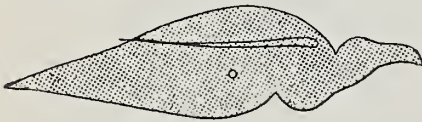


FIG. 65.

Section of a vulture slow flex-gliding.

As already stated this position is apparently identical with that assumed for gliding with speed ahead in an ascending current. In this latter case the angle of incidence is about 90° . In other words the "total pull" acts in a direction at right angles to the surface of the wing, or nearly so. Therefore in slow flex-gliding the unknown force of soarability must also act in a direction approximately at right angles to the surface of the wing.

If a vulture when slow flex-gliding wishes to increase its speed it slightly increases the flexure of its wings. The secondary quills are thereby relaxed, and assume the position shown in fig. 66.



FIG. 66.

Section of a vulture fast flex-gliding.

Thus the wings of a fast flex-gliding vulture are disposed in a way which if imitated by a power-driven aeroplane one would expect to rapidly bring the machine

to earth. That the wings actually assume the position shown is a matter of comparatively easy observation. It is important to realise that the position assumed by the wing is due to air pressure, or more particularly by a pressure exerted by soarable air when under the vulture's wing. Flexing the wing at the carpal-joint results in relaxing the ligaments that hold the secondary quills in position. This relaxing of the ligaments, of itself, has no power of putting the secondary quills in

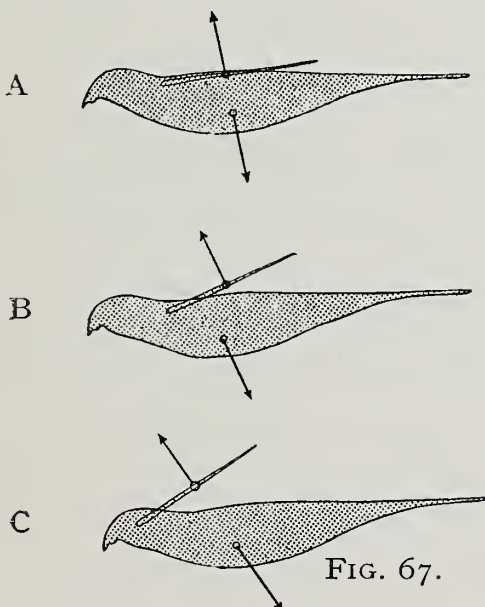


FIG. 67.

Diagram of bird showing position of "pull" and "drag," at A in slow flex-gliding, and at C in fast flex-gliding. At B is shown an imaginary case in which the wings are placed in the fast flex-gliding position, except that they are not advanced. Hence between the "pull" and the "drag" there is a couple tending to rotate the bird round its transverse axis.

their new position. It merely allows the feathers to take the position given to them by the pressure of the air. A little consideration will show that in fast flex-gliding the pressure is exerted at right angles to the surface of the wing, as is the case in slow flex-gliding.

In fig. 67, the disposition of the wing in slow flex-gliding is shown at A. The arrows represent the position and direction of the "total pull" and "total drag." The position of affairs in fast flex-gliding is shown at C. The weight is as before. The resistance to passage through the air is increased owing to the increased speed. Therefore the "total drag" must act in a more backward direction. Hence I have drawn the "total drag" arrow in C pointing more backwards

and less downwards than in A. But the "total drag" must act in a line with the "total pull." In fast flex-gliding the wing is further advanced as I have drawn it at C. Hence, as shown at C, the force is still exerted at right angles to the surface and at the centre of area, or thereabouts. If the bird was to increase speed merely by relaxing the secondaries, as shown at B, a couple would originate tending to cause rotation downwards round the transverse axis. Hence in flex-gliding, the faster the speed the more the wings are advanced.

I have stated elsewhere that during the up-stroke of the double-dip the wing is strongly rotated. Its probable position at the beginning of the up-stroke of the double-dip is shown in fig. 68. Instantaneously after

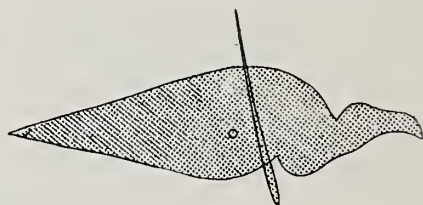


FIG. 68.

Section of a vulture during the up-stroke of a double dip movement.

the double-dip the speed ahead can be seen to be markedly increased. Therefore the bird must have received a push ahead during the double-dip. Therefore during the double-dip movement the pressure must still be exerted at right angles to the surface. If the wing was rotated without first being placed dihedrally downwards it is clear from the foregoing description that the bird would have been suddenly rotated downwards to an excessive degree round its transverse axis. Hence the rationale of the double-dip as a means of increasing speed can, to some extent, be understood. During the up-stroke of the double-dip the bird is perhaps dropping feet foremost through the air. But the position of the centre of effort of the wings and the direction of the pressure is such as to increase speed ahead.

But the increased speed after the double-dip is maintained without any further adjustment or movement on the part of the bird. Therefore we must conclude that the push given by the double-dip initiates an increased rate of use of air energy.

Here we are brought face to face with the mystery of soaring flight. Clear proofs have been given that in sun soarability sun energy is somehow stored in the air. Somehow this stored energy becomes available for doing mechanical work—for instance in driving ahead the flex-gliding vulture.

Before attempting to speculate as to how sun energy can be stored in the air let us consider a method of making a rough estimate of the amount of work that can be done by this stored energy.

In flex-gliding the wing-tips are retired by flexing at the carpal-joint. When viewed from below the digital quills are seen to be directed outwards and backwards. But when the bird is viewed from the side the digital quills may be seen, in certain cases, to be bent upwards. In the case of the lighter birds they usually appear to be lying flat, except that the extreme tips of the digital quill feathers may, under favourable circumstances, be seen to be turned up. In the case of the heavier birds they usually appear to be turned up to a greater degree. This is not always easy to see. If the bird is seen from behind, the wing-tips, owing to their position, appear foreshortened, and the full extent of their upward bend is not apparent. When the bird is gliding past, giving a broadside-on view, and especially before it has reached the exact broadside-on position, the digital quills of the near wing can be seen to be strongly turned up, but only a slight turning up

of the quills of the far wing can be made out. This again is obviously an effect of foreshortening. I have often watched a flex-gliding vulture while travelling in a straight line for long distances, probably as much as a mile or more, and have been able to see the digital quills of the near wing bent up and destitute of any sign of movement. But the black vulture gives better opportunities of observation as it frequently flex-glides at a height of only about 200 metres. The common vulture, on the other hand, rarely flex-glides at a height below 300 metres. The following are my more recent observations on flex-gliding of black vultures :

4th April, 1912. At 1.55.—Vultures circling. A vulture flex-gliding at 8 metres per second. A black vulture flex-gliding beam—on showed one digital quill only turned up. This must have been the first digital quill, which is the most flexible.

18th April, 1912. At 9.30.—A black vulture flex-gliding at low level showed two digital quills turned up.

2.5.—A black vulture fast flex-gliding at low level. All the digital quills were turned up, and their curvature was visible.

21st May, 1912. At 3.0.—Wind west, moving small branches. A black vulture flex-gliding at low level, at very high speed, showed all the digital quill feathers turned up and curved. They all appeared to be bent up to nearly the same degree.

3.45.—Dust storm, slightly yellow. Heavy cloud about.

The appearance of the turning up of the digital quills is shown diagrammatically in fig. 69. This was drawn as the result of an observation earlier than those above quoted. The curvature of each individual feather was distinctly seen

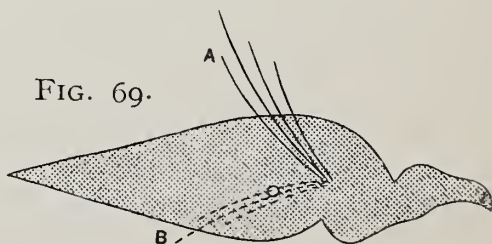


FIG. 69.

Diagram showing position of digital quills in fast flex-gliding. A shows the actual observed position of the quills. At B is shown the position that these quills would take up in the absence of air pressure.

in the black vulture which was fast flex-gliding at low level. The fact that the quills were curved and not

straight, and with the concavity above, proves definitely that their position was due to air pressure and not to wing rotation. As appears from the above observations, the fact that there is less turning up of the quills in slow than in fast flex-gliding proves that the appearance has something to do with the rate at which energy is being taken from the air, and that it is not due to some optical illusion or atmospheric distortion.

That a considerable force is necessary in order to produce the curvature observed is indicated by the following measurements :

An adjutant of 9ft. 6in. span was placed lying on its back on a table. It was found that the following weights were necessary in order to make the quill feathers lie flat :

1st primary quill	..	..	..	20 grammes
2nd " "	..	..	..	30 "
3rd " "	..	..	..	60 "
4th " "	..	..	..	60 "
5th " "	..	..	..	90 "
6th " "	..	..	..	70 "
7th " "	..	..	..	10 "
8th " "	..	..	..	0 "

Obviously, in order to bend the quill feathers beyond the flat position to the position observed in fast flex-gliding, much greater weights would be required. In the case of the quill feathers of the wing of a vulture I found that weights approximating 150 grammes were necessary for the purpose. The weights were placed 2in. or 3in. from the end of each feather.

Therefore sun energy is stored in soarable air to such an extent that it can exert a force approximating to a weight of 150 grammes on each quill feather of a flex-gliding bird. If sun energy is stored in the form of ascending currents then these currents must ascend

with such energy that they can bend up primary quill feathers with a force equal to that exerted by a weight of 150 grammes.

We have elsewhere seen that if soaring flight is due to ascending currents these currents must be small in size and so uniformly distributed, that the bird meets them everywhere as it goes without having to turn out of its course to look for them. Observation of the quill-tip feathers in fast flex-gliding enables us to postulate something more about these currents. So long as the bird has a constant speed the tip feathers have a constant position. They are being bent up by the unknown force of soarability, and they are being bent up constantly. There is no sign of vibration as would be the case if the bird was gliding in and out of ascending currents containing sufficient energy to produce the observed effects. That is to say, if sun energy subserves soaring flight by means of ascending currents, these currents must be so closely packed that, though the quill feather is pressed up intermittently by each current as it meets it (on this hypothesis), there is no time in the passage from one current to the next for the feather to bend down again appreciably. Thus, if the air is suitable for fast flex-gliding flight it acts as if it is (on this hypothesis) tightly packed with ascending currents of great strength. In other words it acts as if, not only in one place but all over the sky, it is ascending *en masse* at a rate of thirty or more miles an hour. In this same air a piece of thistle-down may float showing often scarcely any movement, and in no case any amount or rate of movement proportional to the amount of force exhibited in the bending of the feathers and in the speed of the flex-gliding bird.

It might be suggested that the bird is so shaped that it slips through the air without great resistance and that therefore no great expenditure of energy is involved. This view is contradicted by two facts: Firstly the bent-up position of the digital quills just described. Secondly the phenomena accompanying a double-dip movement. This movement lasts only the fraction of a second. Nevertheless it results in giving a 15 lb. bird a push ahead that increases its speed by several metres a second. To all appearance the increase of speed is instantaneous. If the acceleration could be measured by, for instance, some refinement of the looking-glass method described in Chapter II., we should have a means of estimating the amount of force available. Even if the resistance to speed ahead of the bird was nil the observed sudden increase of speed of a mass of 15 lbs. or more could not be explained by any upward component of the wind that could reasonably be supposed to exist.

Further, it may be noted the air does not act as if the whole atmosphere was ascending vertically at the rate of thirty or more miles an hour. The ascent cannot be vertical, but must be (on this hypothesis) in such a direction that the air presses at right angles to the surface of the wing of the fast flex-gliding vulture. This is the case in whatever direction the vulture happens to be gliding. The wing disposition employed in a vertically ascending current has been described and has been shown to be entirely different from that assumed in fast flex-gliding. That is to say, the position of the wing in fast flex-gliding definitely excludes the idea that soaring flight is due to vertical air currents.

The prevalent idea that soaring flight is due to there being an upward component of the wind of 3ft. or 4ft. per second, of which soaring birds having a good gliding angle are able to take advantage, is a theory that can only be held by one ignorant of what it is that requires to be explained. It is a theory equally incapable of explaining the advancing of the wings in fast flex-gliding, the push ahead received by the bird in a double dip movement, and the turned up position of the digital quills. In other words, it is a theory that fails to explain either the intensity of the force revealed in fast flex-gliding or the direction from which this force is operative. Reasons for doubting whether the more efficient soaring birds have a good gliding angle will be given in Chapter XIX.

The greater includes the less, and not the less the greater. Therefore a theory of soaring flight cannot be satisfactory that merely explains circling, in which, as has been shown, the minimum amount of energy is taken from the air. A theory of soarability must in the first place take account of fast flex-gliding in which form of flight the maximum amount of energy is being used. The facts now described about flex-gliding are not trivial facts to be explained away to suit preconceived ideas. They are the central and essential facts of soaring flight.

Thus we have arrived at the conclusion that in flex-gliding the sun energy stored in the air acts as a constant force. The facts described relating to the regularity of circling, etc., indicate that the force is equally constant in the case of other forms of soaring flight. Further facts in favour of this conclusion will be brought forward in a later chapter.

With the aid of this conception of the constancy of the force of soarability we are now in a position to consider certain factors affecting the angle of incidence.

In the case of aeroplanes the wings have a fixed position in relation to the direction of pull of the engines. The angle of incidence is therefore definitely settled before the aviator leaves the ground. So far as the direction of movement of the aeroplane is due to the pull of the engine there is no change in the angle of incidence during flight.

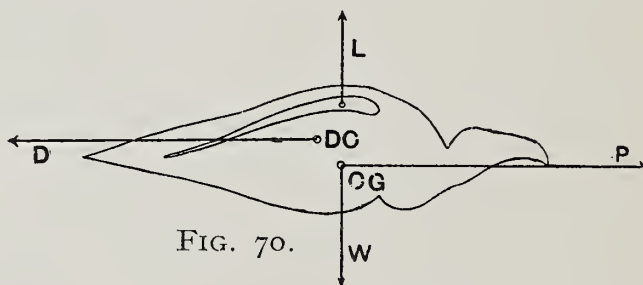
The bird, lacking a motor, has no such definite and simple method of maintaining its angle of incidence.

Let us consider an imaginary case of a bird suspended by a string attached to it at its centre of gravity. Let us further suppose that the air surrounding the bird is destitute of movement. We will suppose that the wings are stretched out horizontally in the position they assume during ordinary gliding flight. Under such conditions the bird has no difficulty in rotating its wings round their long axis. The axis round which the wing rotates is very near its anterior margin. Supposing now the air surrounding the bird is set in motion, and that the bird faces the air current, and let us suppose further, that the wings lie in the horizontal plane so that there is no angle of incidence. If the bird now commences to rotate the wings upwards, *i.e.*, in such a direction that their posterior margins go downwards, then the air begins to press on the underside of the wing. The centre of this pressure is somewhere between the centre of area and the anterior margin. The position of this centre of pressure will vary under different known conditions. In slow flight, at all events, this centre of pressure must be situated

posteriorly to the axis round which the wing rotates. From this it follows that, if no other factor intervenes, rotation of the wings in one direction will tend to result in rotation of the body in the opposite direction. We have therefore to consider by what means a bird can maintain or change the angle of incidence of its wings during flight without subjecting its body to rotation round the transverse axis.

Let us first consider the case of a bird at the commencement of a period of gliding when in flap-gliding flight in unsoarable air. Let us imagine that the bird

P. Pull.
D. Drag.
L. Lift.
W. Weight.
CG. Centre of gravity.
DC. Drag centre.



Vulture flap-gliding in unsoarable air at commencement of a glide.

is travelling horizontally. The bird is being acted on by the four chief forces. Of these the "lift" and the "weight" act at points one vertically above the other as elsewhere explained. The other two forces are the "pull" and the "drag." The "pull" consists of the momentum of the bird. This acts in a horizontal direction at the centre of gravity (see fig. 70). The "drag" consists of the resistance of the body of the bird to passage through the air, plus the resistance due to the action of the air on the wings. The "drag" must therefore act in a horizontal direction backwards. It probably acts at a point slightly above the level of the centre of gravity. But its exact position, that is to say the position of the "drag centre," is unknown. Sometimes at least in slow-flapping flight the head end

of the bird rises during the down-stroke and falls during the up-stroke. The transverse axis round which this rotation occurs probably passes through the "drag centre." In flapping flight there is an increase of transverse axis and dorso-ventral axis stability. These facts suggest that the "drag centre" is situated posteriorly to the centre of gravity. Just as the "lift" and the "weight" act at two points some distance apart one above the other, so, in like manner, it is probable that the "pull" and the "drag" act at different points, one behind the other, thus conferring a small measure of natural stability.

Since the drag consists not only of the resistance due to the action of the air on the wings, but also to resistance due to the action of the air on the body, there can be little doubt that, under the conditions described, it is situated on a slightly higher level than the centre of gravity. If this is the case, there must be a couple between the "pull" and the "drag" that tends to rotate the bird upwards round its transverse axis, in other words, that tends to maintain the angle of incidence.

When a bird is gliding in unsoarable air with loss of height it is probable that no other factor intervenes to maintain the angle of incidence.

But suppose the bird were to glide into a patch of soarable air, and continue gliding with wings at full camber. Then, under these conditions, the "pull" would no longer act at the centre of gravity. It would no longer consist of the momentum. It would consist of the tractive effect of soarable air on the cambered wing. That is to say the "pull" would act on a level with the wings (fig. 71). Hence the above-described

means of maintaining the angle of incidence would no longer be operative. Apart from the wing-tips the wings act not as a resistance but as a source of tractive effort. Hence the "drag" consists not of the action of the air on the wings plus the resistance of the body of the bird to passage through the air as before. It consists of the last-mentioned factor plus such resistance as may be derived from the wing-tips.

The question we have to solve is how the angle of incidence is maintained in soarable air with the wings at full camber. Facts in my possession tend to show

P. Pull.
D. Drag.
L. Lift.
W. Weight.
CG. Centre of gravity.
DC. Drag centre.

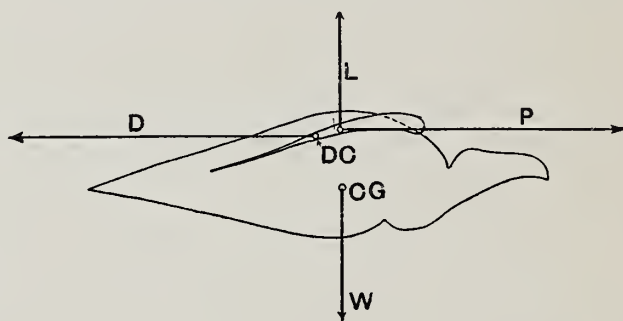


FIG. 71.

Vulture gliding in soarable air
with wings at full camber.

that this function belongs to the digital quills. If a bird is gaining height with wings at full camber the wing-tips are rotated upwards. The air pressure on the underside of the digital quills must tend to lift up the anterior margin of the wing (see figs. 59 and 60). A proof of the truth of this assertion will be found in the fact that the degree of upward rotation of the wing-tip is proportional to the amount of energy being taken from the air.

I have already stated that when circling in fully soarable air with effort to gain height the wings are advanced and placed in a dihedrally-up position. Obviously this disposition must place the wing-tips in the most favourable position for maintaining the angle of incidence (fig. 60). If the bird is circling without

effort to gain height the wings are not advanced but straight. Also the dihedrally-up angle is reduced. With this disposition the wing-tips are in a less favourable position for affecting the angle of incidence (fig. 59).

The graphic records of the tracks of circling birds shown in an earlier chapter indicate that there is commonly loss of speed on the windward side of the track. Visual observation shows also that on the windward side of the circle is the usual position for gain of height. The following observations show that this windward gain of height is due to a voluntary movement, that is to say the bird increases the advancing of its wings on the windward side of the circle. Thereby the angle of incidence is increased with resulting gain of height :

16th November, 1910, at Jharna Nullah. At 10.45.—Wind moving leaves from north-west.

10.50.—Many vultures ease-circling (*i.e.*, with no advancement).

10.51.—Another adjutant circling. Half-dips, but no retirement of outside wing-tip observed.

0.52.—It showed leeward drift and gain of height.

10.55.—It was fast flex-gliding up-wind.

10.57.—Vultures circling show more wing advancement on windward side than at any other parts of the track. Wind west, moving small branches.

11.2.—Vulture ease-gliding overhead. No advancing of wings. No half-dips or retirement of outside wing-tip. Wind moving branches. Rapid drift to leeward of circling birds.

11.5.—Many vultures fast flex-gliding up-wind or beam on. Wind moving branches.

11.8.—Wind less. Vultures ease-gliding up-wind.

11.19.—An adjutant apparently in wind arched its wings. It dropped slowly feet foremost vertically downwards.

11.49.—Vultures overhead, 80 metres up, showed neither half dips nor retirement. There was more advancing than previously, especially along windward side of circle.

In the above cases the wing-tips are kept rotated upwards to their fullest extent. Therefore the air presses on the under surface of each digital quill. The different quills are thereby lifted to different degrees, dependent

on their flexibility, as explained in a previous chapter and as illustrated in fig. 24. This lifting of the digital quills results in a force tending to lift up the anterior margin of the wing. This force acts at a good mechanical advantage if the wings are advanced, and acts at a less advantage if the wings are straight. Supposing the wings are kept straight and the wing-tip is not kept rotated up to its fullest extent, then the air pressure has a decreased lifting action on each quill. Hence the force tending to lift up the anterior margin of the wing is further decreased. There is thus a smaller force expended in maintaining the angle of incidence, and less energy is taken from the air, as illustrated by the following observations :

August 29th, 1911. At 4.25.—A vulture seen descending slowly. Its wing-tips were only slightly rotated upwards. The first digital quill could be seen to be slightly turned up. It remained with the wing-tips in this position during the whole of its descent. It took nearly ten minutes to descend through 300 metres. It was descending in circles, and was in the direction of the Taj.

4.30.—Another vulture descending. Its wing-tips were flat, but not retired (indicating that the angle of incidence was not so much diminished as in metacarpal descent). It took two or three minutes to descend through 300 metres.

Owing to the natural curvature of the quill feathers air must be exerting some pressure on their undersides for them to assume the flat position. As elsewhere described, the wing-tips in metacarpal descent, besides being flat, are retired, thus still further diminishing their action in maintaining the angle of incidence.

In the above cases the same disposition of the wing-tips was assumed for each wing. In the following two observations I saw the effect produced by rotation of a single wing-tip :

19th August, 1911, at Jharna Nullah. At 6.0 p.m.—Wind moving small branches. Some eagles seen flap-gliding. Twice a wing-tip rotation was seen to be followed by a small decrease of the angle of incidence of the wing.

In each of these cases a steering effect was produced. The wing-tip rotation was small and not sufficient to produce a typical dip movement. Neither was there any appearance of a wing depression. The following is a similar observation :

October 8th, 1911, at Jharna Nullah. At 10.0.—Wind south, moving leaves.

10.38.—A vulture made a slight wing-tip rotation. This was seen to be followed by a decrease of the angle of incidence of the affected wing.

I was particularly fortunate in being able to make this last observation. I had never expected to be able to see this movement in a vulture. I was seated in a slight depression in the ground within about ten yards of one or two hundred vultures that were busily eating carrion. Many vultures were descending or gliding near me at low levels.

We are now in a position to understand the cause of the steering effect produced by a dip movement. The evidence now brought forward indicates that the steering action is due to the inside wing being given an angle of incidence inappropriate to its camber. Some facts to be described in the next chapter will be found to be in harmony with this conclusion.

My observations have therefore led to the belief that the wing-tips have two functions : Firstly, steering in the horizontal plane. This is produced by rotation downwards of one wing-tip with consequent loss of speed of the wing whose tip is rotated. Secondly, maintenance of the angle of incidence, both in soarable air and when flap-gliding with effort to maintain or gain height.

Presumably the fact that the primary quills are separate aids the lifting effect while presenting less resistance to forward movement through the air than would be the case if these feathers overlapped.

CHAPTER XII.

THE FLIGHT OF BATS.

In preceding chapters I have brought forward certain facts and certain inferences relating to the flight of birds. The correctness of my description of the facts can best be substantiated by a repetition of the same observations. But the correctness of the inferences can best be proved by bringing forward observations on other kinds of flying animals. Bats differ from birds in their habits and in their mechanism for flight. It will be interesting to see how far their flight manœuvres resemble those of birds, and how far my inferences as to the nature of bird flight are substantiated by observations of bats.

My observations have been carried out on a species of fruit-eating bat known as the "Flying-fox" (*Pteropus medius*), fig. 72.



FIG. 72.

Outline of flying-fox (*Pteropus medius*) showing the bones of the arm and leg employed in supporting the wing membrane. I., thumb; II., III., IV., and V., the other elongated digits.

I obtained the following measurements from three different specimens of the flying-fox :

	I.	II.	III.
Weight	923 grammes	860 grammes	640 grammes
Span	51½ in.	48½ in.	44 in.
Area of one wing .	1.21 sq. ft.	.962 sq. ft.	.914 sq. ft.
Width of wing ..	8½ in.	8 in.	8 in.
Loading .. ..	.84 lb. per s.f.	.98 lb. per s.f.	.77 lb. per s.f.

The membrane of the wings of these animals is so soft and extensible that it is difficult to be certain how

far the wing measurements given above correspond to the size of the wings in actual flight.

A colony of between two and three hundred flying-foxes lives during most of the year in a garden in Agra known as the Company Garden. During the daytime these animals may be seen hanging head downwards from the branches of a large tree. During September, October, and November 1911, these bats used to commence their flight when it was almost dark. After flapping and gliding round the tree for a few minutes they used to fly off, flapping in solitary flight to their feeding grounds. During December and January the whole colony disappeared. In February a few returned, but during the hot weather they did not start until it was almost completely dark, so further details of their mode of flight could no longer be observed.

The structure of the wing of the bat as compared to the wing of a bird is extremely complicated so far as the numbers of muscles present are concerned. Despite the large size of the flying-foxes that I dissected I found that the majority of the tendons were scarcely thicker than a bristle.

Most of the muscles have flexing or extending functions. The flying-fox has no power of rotating the wing-tip. There is a mechanism for rotating downwards or turning downwards the middle third of the anterior margin of the wing. This is the part of the anterior margin that is supported by the first two digits and that extends in front of the main bony framework (fig. 73). By turning downwards this part of the margin the camber can be increased. The part of the wing membrane that can be thus turned down is, in the flying-fox, about one-sixteenth of the whole wing area.

The mechanism in question consists of two tendons in a common sheath when near the muscle. These separate distally, and run to digits I. and II. By pulling on this double tendon the digits are depressed.

There is also a muscle whose action is to bend downwards the outer part of the wing. The bending occurs at the carpal-joint, thus producing the appearance of arching that is seen in the flapping flight of this animal.

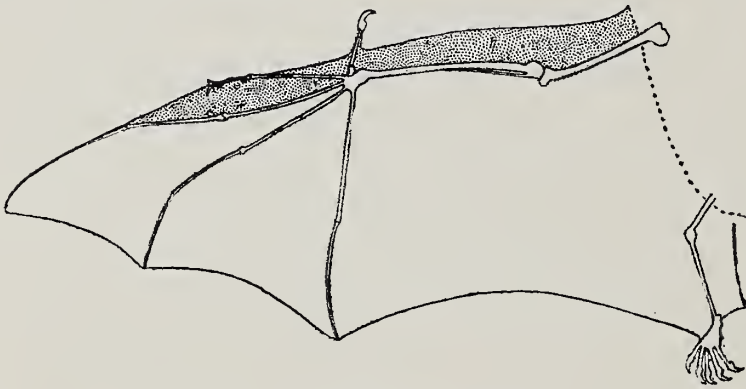


FIG. 73.

Wing of flying-fox (*Pteropus medius*) showing bones supporting the wing membrane. The shaded area indicates the part of the wing membrane that can be moved downwards by movement of the first and second digits, thus causing a change of camber.

That there is a general similarity between the flight of flying-foxes and the flight of birds is shown by the following extracts from my diary :

September 24th, 1910, at Company Garden. At 6.30 p.m.—Flying-foxes seen clearly to move wings quicker during the up-stroke than during the down-stroke. This, combined with the arching at the end of the down-stroke, causes the illusory appearance of a pause during the beat. On several occasions a flying-fox seen to cease flapping before making a turn (in the horizontal plane). In each case it recommenced flapping immediately it had turned. A flying-fox seen gliding with wings arched. It was seen to check its speed by advancing the wings, which were still arched. Advance of wings on down-stroke seen in slow flapping flight. Flying-foxes frequently seen gliding downwards, at a small angle with the horizon, with wings arched and at moderate speed. On one occasion a flying-fox seen to glide downwards but with wings even and dihedrally down. It was gliding down at a small angle with the horizon, and its speed was seen greatly to increase.

September 26th, 1910, at Company Garden. At 6.30.—A flying-fox half flapping showed advancing of wings with consequent rotation round transverse axis. This was for checking speed. A flying-fox gliding with wings arched showed increase of arching of inside wing for steering. A flying-fox gliding downwards (at a small angle with the horizon) with wings nearly even showed a whole wing depression for steering.

I have on other occasions seen increase of arching for steering in flapping flight. The wing appears to be more arched at the end of the down-stroke on the side to which the bat wishes to go. In the case of a flying-fox gliding downwards with wings arched I have noticed that increase of arching was followed by increased rate of loss of height.

As in birds, the dihedrally-up position is used for causing rotation upwards, as illustrated by the following observations :

October 2nd, 1910, at Company Garden. At 6.30.—A flying-fox when gliding was seen to put wings in slightly dihedrally up position for rotation round transverse axis to check speed before stop-flapping. Flexing with arching seen for checking speed in gliding. In flapping flight increased arching of one wing seen for steering. This was again seen. On three occasions I formed the impression that the wing is slightly flexed on the down-stroke in flapping flight.

Despite a somewhat intimate acquaintance with the flight of vultures I have only on one or two occasions seen one of these birds make a sudden movement to avoid another. No doubt, owing to their habit of flying together, they are expert in judging the movements of other birds. Flying-foxes show no such gregarious habits when flying. They are only together in the air for a few minutes after leaving the tree on which they roost. Hence, despite my comparatively slight acquaintance with these animals, I have very frequently seen them make sudden movements to avoid one another. On one occasion I have seen them apparently in collision in the air. These sudden movements can be seen to result in the beat of the wings being

horizontally to and fro. In a few cases only I have seen that this is preceded by rotation round the transverse axis caused by advancing the wings.

The following extracts from my diary may be quoted:

November 15th, 1910, at Company Garden.—A flying-fox seen gliding with wings arched. Increase of arching was followed by increased rate of descent. A flying-fox gliding with wings flat showed a wing depression. This was a very slight movement. (Apparently it was a steering movement.) Two flying-foxes noticed in collision. As a result there appeared to be rotation both of wings and body to check speed. Flapping seen without arching. Apparently it was half flapping to check speed. A flying-fox seen to advance wings, and rotate round transverse axis. Then it rotated round its dorso-ventral axis. It gave me the impression that the object of this manœuvre was to turn suddenly horizontally. (Each of these two rotations was through about 90° . A more detailed account of a similar proceeding in the case of a cheel has been given in Chapter X.) In arching the posterior margin of the wing seems to go up.

In the case of birds I have shown, in a preceding chapter, that a particular angle of incidence is appropriate to a particular amount of camber. For instance if the angle of incidence is diminished while the camber is maintained then there is loss of speed, as seen both in metacarpal descent and in ordinary steering by dip movements. If on the other hand the angle of incidence is diminished, and if at the same time the camber is proportionately diminished, then there is increased speed, as seen in flex-gliding. I have now to describe facts that show that flying-foxes make a similar use of changes of camber.

I have already stated that the anterior part of the wing area is supported by the first two digits. By moving these two digits up or down camber can be decreased or increased.

As the thumb supports this anterior part of the wing membrane (see fig. 73), and extends beyond it, it is obvious that observations of the position of the thumb

during flight might give a clue to changes of camber that in themselves are invisible. Such observations are very difficult to make, both owing to the speed of the bat and owing to the dimness of the light. The presence of the full moon is no advantage, as it seems to make the bats start later than usual. Causing them to fly by throwing stones during the day results in hurried flight of no use for my purpose. It rarely happens that a flying-fox when gliding remains near enough to be observed for so long as a second. At the time when the majority of the flying-foxes start on their evening flight it is too dark to see any traces of the thumbs. But some minutes before their time of departure a few individuals flap or glide from one tree to another. With practice and by careful observation glimpses may sometimes be had of the position of the thumb in these cases. These observations are among the most difficult I have made.

My earlier observations are as follows :

September 22nd, 1910.—A flying-fox flapping downwards with wings dihedrally down, or arched, or both, the thumbs appear to be pointing downwards. When flying upwards the thumbs appear to stick out straight in front (*i.e.*, camber at minimum or abolished). In horizontal flapping flight they appear to stick out straight in front with very slight inclination downwards.

September 24th, 1910.—In steering (in the horizontal plane) I formed the impression that, besides arching the inside wing, the thumb of this wing is also turned down.

September 24th, 1911.—A flying-fox seen to increase arching and flexing of wings for steep descent. The result was that, besides gliding ahead, it was noticeably dropping through the air. This was carpal and elbow-flexing. No flexing occurred at the shoulder joint because there was no rotation round the transverse axis. It was the equivalent of carpal descent. Another flying-fox seen gliding downwards with wings strongly flexed and arched. Its thumbs were pointing downwards. This was shortly afterwards seen in another case. A flying-fox gliding with wings arched seen to steer by increase of arching of inside wing. Thumbs were again seen pointing downwards in carpal descent.

September 25th, 1911.—In several cases I saw that in flapping flight the thumbs are directed horizontally forward. In these cases the animal

was flying either horizontally or at a slight upward angle with the horizon. When gliding with wings slightly arched, and with no appreciable loss of height, the thumbs are directed forward with a very slight downward inclination. This was again seen. When gliding with small loss of height the thumbs are directed downwards and forwards.

From this we see that when flying-foxes are gliding horizontally the camber is at a minimum. When arched gliding, with slight loss of height, there is medium camber. When gliding downwards steeply—certainly without increase of speed, and probably with loss of speed—the camber is at a maximum. Previous observations have shown that in this latter case the angle of incidence is diminished. Hence it appears probable that we again have a case of checking speed by giving the wings a degree of camber unsuited to the angle of incidence. Further observations show that flying-foxes make another use of change of camber:

September 29th, 1911.—A flying-fox gliding upwards had thumbs horizontal.

September 30th, 1911.—A flying-fox gliding downwards had thumbs pointing downwards. A flying-fox gliding horizontally had thumbs very slightly inclined downwards. When gliding just before perching they pointed strongly downwards. Another also showed thumbs directed downwards just before perching. Another gliding horizontally showed thumbs directed forward nearly horizontally. A flying-fox gliding showed thumbs pointed downwards just before poise flapping before perching. A flying-fox making half-flaps had thumbs directed horizontally forward.

October 2nd, 1911.—A flying-fox gliding horizontally seen to turn thumbs downwards to check speed. A flying-fox gliding had thumbs directed slightly downwards. Then, to check speed just before perching, the thumbs were turned strongly downwards. Then it began poise flapping and perched. This again seen three times. Thumbs seen turned slightly downwards for flapping at low speed. Flexing and increased arching of inside wing seen for steering in flapping flight.

October 4th, 1911.—Thumbs seen stretched out horizontally in horizontal flapping flight. This seen again repeatedly. A flying-fox gliding downwards with wings arched had thumbs turned down. A flying-fox gliding seen to increase arching of inside wing for steering. A flying-fox in flapping flight seen to steer by increasing the arching during the down-stroke of the inside wing.

October 5th, 1911.—A flying-fox seen to direct thumbs downwards in gliding just before perching. A flying-fox in flapping flight seen to direct thumbs downwards just before perching.

These observations prove that in gliding before perching there is an increase of camber. But at this time the wings are advanced. This advancing produces rotation round the transverse axis, and the angle of incidence is consequently increased. Therefore, unless the movement is purposeless, it appears probable that in this case increased camber prevents dropping through the air or has some other beneficial action when speed is checked by the large increase of the angle of incidence.

Parenthetically I may state that during this period before perching (whether flapping or gliding) the hind legs come apart. No doubt this is due to the effect of the pull on the wing membrane caused by advancing the wings. Just before perching the legs are again brought together and advanced. In ordinary flight the hind legs lie parallel and close together.

From the above observations it appears probable that arching to a large extent is necessarily associated with turning down of the thumbs. In the human hand the thumb and first finger can be rotated downwards to a slight extent (supposing the hand is held palm downwards) without the movement of the middle finger. The facts described suggest that the same relations hold in the case of the digits of the flying-fox.

The use of change of camber seems to be the same whether the animal is flapping or gliding. I have previously shown that steering in flapping flight is caused by increase of arching of the inside wing during the down-stroke. It is an interesting possibility that this increase of arching is a sign of momentary increase of camber. If this increase of camber exists it must coincide with a decrease of the angle of incidence, for the increase of arching is accompanied by a small

amount of flexing, and owing to the structure of the bat's wing, flexing at any joint must slacken the membrane and so diminish the angle of incidence. It will be at once objected that we have no right to speak of an angle of incidence during flapping flight, but the force of this objection will be lessened by the following considerations.

When an adjutant bird is observed in a gliding period of flap-gliding flight in end-on view the wing-tip feathers are seen to be spread out like the ribs of a fan as illustrated in fig. 24. That is to say, the wing-tip is rotated upwards in order to maintain the angle of incidence. This is always the case when there is effort to maintain or gain height. When gliding with loss of height, with or without arching of the wings, the wing-tip is rotated upwards to a lesser degree so that the digital quills lie nearly or quite in the same plane. Supposing the bird commences flapping the wing-tip feathers remain spread out as before like the ribs of a fan. I have long suspected that they retain this disposition during the whole of the up-stroke and during the whole of the down-stroke. I have recently been able to see definitely that this is the case both in adjutants and in vultures when in ordinary flapping flight with effort to gain or maintain height. In a recent observation the degree of spreading out of the wing-tip feathers appeared to be slightly less in flapping than in gliding with maintenance of height. My observations relate to birds observed flapping at low levels. It does not necessarily follow that the tip feathers are turned up when flapping at high levels when there is more effort to gain speed than height. The amount of retirement of the wing-tips during flapping appears to be

different under different conditions, but what these conditions are I have not yet been able to determine.

This turning up of the wing-tip feathers during flapping must be due to air pressure. At first sight it is difficult to understand how such pressure can cause this turning up during the up-stroke. But it must be obvious that in gliding with effort to maintain height the spreading out of the feathers is not due to air pressure from below but to the air pressure due to there being speed ahead. That is to say it is due to air pressure from in front. When flapping this pressure from in front must remain during the up-stroke and consequently the tip feathers can remain spread apart if the wing-tip is kept rotated upwards. But if the pressure from in front acts thus in supporting the tip feathers it must also act on the under surface of the wing generally. That is to say, during the up-stroke the bird is still getting lift from the air in virtue of its speed ahead. In Chapter IX. I brought forward grounds for believing that flapping flight consists of gliding with flapping superadded. The considerations now brought forward support this conclusion.

But it does not follow, in all species of birds, or always in adjutants and vultures, that the wing-tip is kept rotated upwards during flapping flight. The Blue Heron and another species of wading bird known to me by sight have an unusually slow rate of beat, and flap with the wings arched throughout the stroke and with the wing-tips flat. Also in these birds the up-stroke terminates unusually early. Thus when the up-stroke ends the wings have scarcely risen to the level of the back of the bird. These last two facts strongly suggest that in these birds flapping occurs

with a smaller angle of incidence (so far as gliding is concerned) than is the case in the flapping flight of vultures and adjutants. In Chapter XIX. reasons will be given for believing that the angle of incidence of the Blue Heron is less in gliding flight than the angle of incidence of vultures and adjutants.

Although my remarks on camber deal not with new principles, but with new applications of principles already known, it is probable that further knowledge of this subject is attainable, and that it might be obtained in other ways than by observation of birds or bats.

For instance it is possible that information might be obtained by experiments with a glider. For this purpose a biplane glider might be constructed having a means of adjusting independently the camber of the wings during flight. If during a glide the camber of the two wings of one side was increased one would expect a steering effect towards that side to occur. Experiment would be necessary to find whether a means of altering the angle of incidence would be required in addition in order to produce this effect. One would expect that steering in the horizontal plane thus produced to cause less canting; that is to say less drop of the wing whose speed is checked than would be caused by certain other methods of steering. Further, if the camber of both the wings of one of the planes was increased during a glide, one would expect rotation round the transverse axis to be produced. That is to say, if the camber of the wings of the upper plane was increased, one would expect the biplane to tend to glide upwards. If the camber of the wings of the lower plane was increased, one would expect the glider to glide downwards. In other words one would expect

these changes of camber to furnish a means of maintaining longitudinal stability.

From the above description it is clear that flight manœuvres of the flying-fox resemble those of birds so far as the structure of their wings permits. By finding that bats make similar uses of change of camber to those described for birds some support as to the correctness of my inferences is obtained.

A striking difference between the habits of bats and birds is that birds are often at least diurnal while bats are nocturnal. It might be suggested that there is something in the structure of the bat's wing that makes it unsuitable for daytime flight in soarable air. But in certain rare cases bats are known to have diurnal habits.

Andrews¹ has observed a species of flying-fox (*Pteropus natalis*) that lives on Christmas Island and that flies and feeds by day. Another species of flying-fox (*Pteropus conspicillatus*) from Fitzroy Island flies in the daytime. Moseley² states that yet another species of flying-fox (probably *Pteropus keraudrenii*), which occurs in Fiji, Samoa, and the Caroline Islands, appears on the wing in the early afternoon in full sunlight.

Probably the absence of enemies in island life is the reason why bats have in these cases adopted diurnal habits.

My observations relating to changes of camber in bats were made under very unfavourable circumstances. It was always difficult, in the deepening twilight, to see any change in the position of the thumb on which change of camber depends. Recently (July, 1912) I have been able to repeat and confirm my observations

¹ "A Monograph of Christmas Island," by Dr. C. W. Andrews, 1900, page 25.

² "Notes by a Naturalist on the *Challenger*," by H. N. Moseley, 1879, page 291.

in full daylight when it was perfectly easy for me and for my friend Dr. G. E. Nicholls who was with me to see the above changes during flight. From a distance of about half a mile we happened to see a large swarm of flying-foxes circling high in the air over the Company Garden and flying in all directions at about 6.30 in the evening. We went to investigate. It transpired that a small boy armed with a "galail," a kind of bow used as a catapult, had aimed at a bees' nest that was hanging in a tree and had struck it with a mud pellet. The bees swarmed out and, fortunately for the boy, decided to put the blame on the flying-foxes and attacked them. The flying-foxes, after flying in some cases for nearly a mile as we learnt afterwards, were returning to their tree when we arrived. A few insects, apparently bees, were still buzzing about near the top of the tree. The flying-foxes were continually settling and starting again. Thanks to the daylight it was easy to see the position of the thumb even in cases in which the animal was nearly overhead. We saw the thumbs flat for horizontal flight and turned down for poising more often than I could count. As many flying-foxes had flown to an unusual height we frequently saw them gliding downwards with wings arched and thumbs down. Increase of arching of one wing for steering, increase of arching of both wings for hastening rate of descent, were seen. In short, by this singular incident, all the flight manœuvres seen previously with so much difficulty were now seen with ease.

CHAPTER XIII.

THE FLIGHT OF FLYING-FISHES.

The most important inference that can be drawn from my observations is one that has been implied rather than expressed in the preceding chapters. The regularity of soaring flight as exemplified by the circling of cranes, the constancy of the pressure exerted by soarable air on the wing-tip feathers of the heavier birds, in fast flex-gliding besides other facts, seem to indicate that in fully soarable air every minute portion is as ready as any other minute portion to furnish energy for soaring flight. The present chapter will be found to contain further evidence in favour of the truth of this conclusion. Exceptions to the rule will be found in my description of instability.

Many observers who have seen flying-fishes darting like arrows in all directions over the surface of the sea, at high and uniform speed, have attempted to discover the nature of the invisible motor by which they are propelled. It was natural that, after my study of soaring birds the idea should occur to me that these fishes get energy from the air. But despite my training in observation of birds it was some time before my eye got into proper trim for observing the flight of flying-fishes and before facts were discovered bearing on the nature of their flight.

Many papers have been published on the flight of the common flying-fish (*Exocætus*), some of which appear to contain unduly definite conclusions based on none too definite observations. Most of these papers

are to a great extent occupied with the question whether or not flying-fishes can indulge in true flapping flight. The majority of writers on the subject have decided this question in the negative sense. Slight movements of the wings that have been observed in some cases are stated to be vibrations caused by movements of the tail, etc. It is generally supposed that the flight of the flying-fish consists merely of a jump out of the water, lengthened out by the supporting power of the wings, that there is no extraneous supply of energy or propulsive effort, and that the animal falls headlong into the water as soon as its momentum is exhausted.

But when we consider the distances covered by flying-fishes, their high speed, and the apparent uniformity of the rate at which they move, it becomes difficult to accept this view in the light of our present knowledge of aeronautics. The usual length of flight, or at least of the longer flights, is stated to be from 100 to 200 metres. Flights of 450 and 800 metres have also been recorded. One observer states that he has seen them fly for a mile. Now it is conceivable that if propelled by a sufficiently strong force an arrow might be caused to fly for a mile. But it is inconceivable that it could be caused to fly for a mile if it was propelled horizontally. It would have to be directed upwards. It would require a trajectory such that during its flight it would reach a height many metres above the level from which it started. Flying-fishes show no such trajectory. Most frequently, and at least in a calm sea, they fly at an apparently uniform height of 2in. or 3in. above the water. No doubt the fact that they are supported by their wings would diminish

the necessary trajectory, but it could scarcely abolish the necessity for its existence. In its general outline the flying-fish has a striking similarity to a monoplane, but it is a monoplane that appears to fly horizontally unaided by a motor.

Two questions arise: First, is the above description true? and secondly if true, what is the source of energy of the flight?

Before describing my own observations, I propose to refer to those of other observers.

Moebius¹ states that flying-fishes make no true flapping movements of their wings. The wing vibration seen as they rise from the water he states to be due to air striking alternately the upper and under surface of the wings. That is to say the wings flutter like a flag in the breeze. If this is the case this fluttering must tend to check speed. So long as it lasts the wings cannot be supporting the animal efficiently. It is to my mind almost inconceivable that such an efficient glider as the flying-fish could commit such a *faux pas* at the commencement of its flight. Moebius has observed that the tail hangs downwards during flight, that is to say that the hind wings are carried on a lower level than the front wings. Presumably this disposition is advantageous in that the lift of the hind wings is not disturbed by air draughts from the front wings. He also states that flying-fishes fly further against the wind. Some observations that I am about to describe will be found to tend to support this statement. He has only observed steering movements in cases in which the wind was abeam. That is to say they only steer in order to turn up into the wind. On the other hand,

¹ "Die Bewegungen der fliegenden Fische durch die Luft" (*Zeitschrift f. Wissensch Zoologie*, Vol. XXX., Suppl., 1878, page 242).

he states that they may travel on a curved course if the tail is hanging down into the water. I have seen a flying-fish follow a curved course when flying with the tail occasionally touching the water. And I have also seen flying-fish, when clear of the water, travelling on a curved course.

Dahl¹ states that observed movements of the wings are due to the to-and-fro movements of the tail as the fish leaves the water.

Jordan² makes a similar statement. Referring to the flight of a large species of flying-fish (*Cypsilurus californicus*), he says: "On rising from the water the movements of the tail are continued until the whole body is out of the water. When the tail is in motion the pectorals (*i.e.*, the front wings) seem in a state of rapid vibration. This is not produced by muscular action of the fins themselves. It is the body of the fish which vibrates, the pectorals projecting farthest showing the greatest amplitude of movement. While the tail is in the water the ventral fins are folded. When the action of the tail ceases the pectorals and ventrals (hind fins) are spread out wide and held at rest. They are not used as true wings. . . . When the fish begins to fall the tail touches the water. As soon as it is in the water it begins its motion and the body with the pectorals again begins to vibrate. . . . The small species fly for a few feet only, the large ones for more than an eighth of a mile. These may rise 5ft. to 20ft. above the water."

These statements may be criticised on the following grounds: The rudder-like movements of the tail are

¹ "Die Bewegungen der fliegenden Fische durch die Luft" (*Zool. Jahrbuch*, Abt. f. Syst. Vol. V., Jena, 1891, page 679).

² "Guide to the Study of Fishes" (Hott and Co., New York, 1905) and "Fishes of North America" (*Bulletin No. 47 of United States National Museum*, page 730)

from side to side. The fluttering of the wings is up and down. The movements of the tail may occur in cases in which no fluttering of the wings takes place. Some years ago during a voyage from Bombay to Marseilles when the sea had a glassy surface owing to the complete absence of wind, I frequently noticed that flying-fish after starting ceased the wagging movement of the tail and then the tip of the tail touched the water several times at regular intervals. Each time it touched the water it made a small circular ripple. The circles thus produced overlapped. It is probable that the appearance was due to an up and down motion transmitted to the tail by the beating of the wings. So far as I recollect when this occurred there was a slight swell. During my recent voyage between Marseilles and Bombay I did not observe this phenomenon. Glassy surface of the sea was only observed in the absence of swell, and wing movement only occurred rarely or not at all under these conditions as will be described below. The wagging of the tail causes a double line of ripples in the wake of the emerging fish quite different in appearance from the overlapping circles above mentioned.

Ahlborn¹ states that the weight of the flying-fish is too much to be lifted by flapping, and that the muscles for moving the wing are far too small. He quotes from Moebius the following ratios representing the relative weights of flight muscles in different animals :

				Weight of			
				Weight of Body.		Pectoral Muscle.	
Bird	..	..	..	6.22	..	..	1
Bat	..	..	..	13.6	..	..	1
Flying-fish	..	..	..	32.4	..	..	1

But in considering these ratios we must ask what the wing muscles are required for in different cases.

¹ "Der Flug der Fische" (*Zool. Jahrbuch*, Abt. f. Syst., Vol. V., Jena, 1897, page 329).

The bird requires its wing muscles for prolonged flight. It also uses its wing muscles for rising from the ground. Bats also can use their wing muscles for this purpose, and, as I have observed, can start from the ground without first running forward on their hind legs. Flying-fishes, on the other hand, get up speed for starting by means of movement of the tail. If their wing muscles are not strong enough for starting or for prolonged flight, they may still be useful (and used) during the short period of flapping that accompanies starting under certain atmospheric conditions, as is about to be described. With regard to the weight being too much to be lifted by flapping flight this is scarcely borne out by actual measurements. Durnford states that a large specimen of a flying-fish weighed just over 1 lb., and that its wing area was 62 square inches. This gives a loading of 2.3 lbs. per square foot. Ducks fly very well with an almost equally heavy loading (2.28 lbs., according to Maxim).

Durnford¹ quotes Burne as stating that the pectoral muscles of the flying-fish are four and four-fifth times as large as the similar muscles of an allied fish that has no power of flight. Humboldt galvanised the muscles of the front wing of the flying-fish, and found them to be five times stronger than the muscles of the hind wings. Ahlborn states that a living fish held in the hand flutters its wings much as a moth would do under similar circumstances. Seitz² gives the rate of beat of the wing of the flying-fish as from ten to thirty per second. It may be asked, what are the enlarged muscles of the wing for if not for flapping? Ahlborn states

¹ "Flying-fish Flight and an Unfixed Law of Nature" (*Annals and Magazine of Natural History*, Seventh Series, 1906, Vol. 17, page 158) and "The Flying-fish Problem" (in the same magazine, Vol. 18, page 334).

² "Das Fliegen der Fische" (*Zool. Jahrbuch*, Abt. f. Syst., V., Jena, 1891, page 361).

that in the daytime flying-fish rise to a height of one metre above the water as a maximum, but that during the night they fly from five to six metres above the water level. If this occurs in a rough sea and a strong wind their rising to this height might be due to their taking advantage of ascending currents. But there seems to be a consensus of opinion that they fly on board ships more often at night-time than by daylight. Rough seas may occur in the day as well as at night. If their flight to such heights as five metres is merely due to taking advantage of ascending currents reflected up from the waves it is not at all clear why they should fly higher at night. The facts at present known suggest that they may have a greater power of flapping flight than is commonly suspected. It would be interesting to know whether flying-fishes fly on board a ship at night in calm weather. I have heard contradictory statements made on this point.

But in any case the more usual course for the flying-fish is that it glides at an apparently uniform height of 2in. or 3in. above the water. Ahlborn makes the ingenious suggestion that it maintains this constant height by a gradual increase of the angle of incidence. The suggestion is an interesting anticipation of my discovery that in unsoarable air cheels and vultures do the same thing. Under favourable circumstances the gradual and uniform increase of the angle of incidence during a glide may be readily observed. Ahlborn states that during the flight of the flying-fish it hangs its tail down more and more, thereby indicating the increase in the angle of incidence. But my own observations show that there is no gradual hanging down of the tail. At the end of a glide, in calm air, the flying-fish may

hang down its tail, and thereby check speed. But this increase of the hanging down of the tail occurs somewhat suddenly, and only near the end of a glide. In unsoarable air no vulture could glide horizontally for half a mile by the expedient of increasing its angle of incidence. The distances flown by flying-fishes are far too great for their constant height above the water to be explained in this way. Ahlborn's suggestion will not explain cases that I am about to describe in which the flying-fish flies against a wind at high speed with the tail not hanging down but carried on a level with the front wings.

Durnford, on the other hand, thinks that flying-fishes flap not only at times when flapping can be seen, as they leave the water, but also during their flight, when the wings appear to remain at rest. He thinks that under these conditions the wings are in such rapid vibration that the flapping can be no longer seen. He mentions the loud buzzing sound always heard when the fish fly over or near a boat. But it appears to me that when flying over a boat the flying-fish is likely to be frightened and in a hurry. It is therefore likely to be flapping under such conditions if it has the power of flapping flight. There is no reason to assume that this is any other than the ordinary flapping such as occurs frequently when leaving the water, and at the usual rate of beat. Durnford also states that in certain cases the wings of flying-fishes appear dim. He explains this by supposing that their wings are in rapid vibration. I entered in my notes a case in which the wings of flying-fishes appeared to me dim. But I also noted that at the time I was suffering from fatigue due to too long continued observation. The glitter of

the sunshine on the water in a tropical sea adds to the difficulty of observing flying-fishes and there is no great wonder if sometimes their outlines appear vague and indistinct. Durnford quotes Egbert as stating that flying-fishes flap at the moment of leaving the water, but that "this flapping motion of the fin-wings is not, however, long maintained, but as soon as the fish is well started in the air, apparently passes into a vibratory motion of the appendages so rapid as to be almost beyond human visual perception." In reference to this assertion of ultra-rapid vibrations I may quote the following observations of my own :

17th December, 1912, in Arabian Sea. At 9.0.—Wind northerly. White tips to waves. A flying-fish seen to rise flapping. It flapped for a distance of about 20 metres in a northerly direction. Then it turned through a right angle rather sharply towards the west, and glided for about a 100 metres before dropping into the water. The outside wing-tip was seen to be turned up at the moment of turn.

21st December, 1912, in Red Sea. At 2.10.—Wind on port quarter. White tips and spray blowing off waves. A large flying-fish, while gliding, showed up-turn of one wing-tip while on a straight course. Length of glide, $4\frac{1}{2}$ seconds.

The extreme tip of the wing of the flying-fish is formed of very thin and flexible membrane. It is difficult to believe that it is not always turned up during flight. But its position during flight is very difficult to observe. The above were the only two occasions on which I was able to see its turned-up position. In each case I was only able to see the turned-up position of the tip of one wing. This is probably due to the wing observed having been in a better position as regards illumination, or to the fact of my attention having happened to be concentrated on one wing only. Thus there is no adequate reason to suppose that only one wing was turned up. Had the wings been in rapid up and down motion at

the time I consider it would have been impossible for me to have seen a turned-up position of the wing-tip. The observations therefore amount to a proof that in these particular cases the wings were not in rapid vibration. Ultra-rapid vibration it may be remarked can easily be seen and recognised in the case of insects. It is not clear why such vibrations should produce an appearance of rest in the case of flying-fishes.

Ahlborn states that almost all observers agree that the course of the flying-fish follows the surface of the waves. Ahlborn denies that this is any proof that the flying-fish steers up and down. He says that the air is moved up and down by the movements of the waves, and that the up and down movement of the flying-fish is caused by the movement of the air in which they are supported. Others, perhaps in too great a hurry to arrive at an explanation, assert that flying-fishes maintain their speed by taking advantage of rising currents of air reflected up from the tops of waves. There is a certain amount of incompatibility between these two views. If the up and down movement of the flying-fish is due to an up and down movement of the air then the fish cannot be getting speed ahead from this movement. If it is getting energy from the air, and if it does so by means of ascending currents, then these ascending currents must be a movement apart from the movement of the mass of the air as the latter rises and falls in harmony with the wave motion. If waves are present in the absence of wind (for example, in the form of a swell), then it is obvious that the air must be moving up and down, as stated by Ahlborn, and must carry flying-fishes up and down with it. But it is not quite clear how far

this conception accurately represents the actual state of affairs in a strong wind. Besides an up and down movement of the air, local currents having an upward trend will also exist on the windward sides of the waves. I have on one occasion seen a flying-fish in a wind suddenly lifted, apparently by such a current, as it reached the top of a wave. But it is an exceptional occurrence for this lifting action to be visible. On the other hand a proof of the up and down movement of the air as postulated by Ahlborn is given by the following observation :

17th February, 1912, near south end of Red Sea. At 3.30.—Wind less. No white tips to waves. Several birds of brown colour seen flap-gliding up-wind one or two metres height above the water. Their course was up and down, following the surface of the sea. They often glided uphill and flapped downhill. This was seen in three consecutive periods of gliding. Then the reverse occurred.

With regard to Ahlborn's statement that flying-fishes cannot steer up and down, I may quote the following observations :

17th December, 1912, in Arabian Sea. At 9.0.—A flying-fish seen to jump nearly vertically out of the water to a height of two metres. Then it glided off horizontally—that is to say, it rotated suddenly round its transverse axis.

21st December, 1912. At 2.38.—A flying-fish jumped from the water to a height of one metre. Then it rotated round transverse axis till body was horizontal. Then it glided ahead.

It may be noted that leaving the water by a vertical jump, as in these cases, is quite unusual. Flying-fishes usually fly out at a small angle with the water. For an appreciable interval the tail remains in the water after the body has emerged. The tail, while in the water, is vigorously wagged to-and-fro causing an increase of speed. On another occasion I have seen a flying-fish make a sharp turn round the transverse axis as it reached the top of a steep wave. It is difficult to believe that this was not due to a voluntary adjustment.

The suggestion that flying-fishes get energy by meeting upward currents at the top of each wave obviously does not explain a flight of half a mile over a smooth sea where there are no waves. In the presence of wind and waves it is impossible to deny that the upward trend on the windward side of each wave may not be of assistance. But, as a matter of fact and observation, flying-fishes may fly long distances along the trough of a wave or along the leeward side of the wave

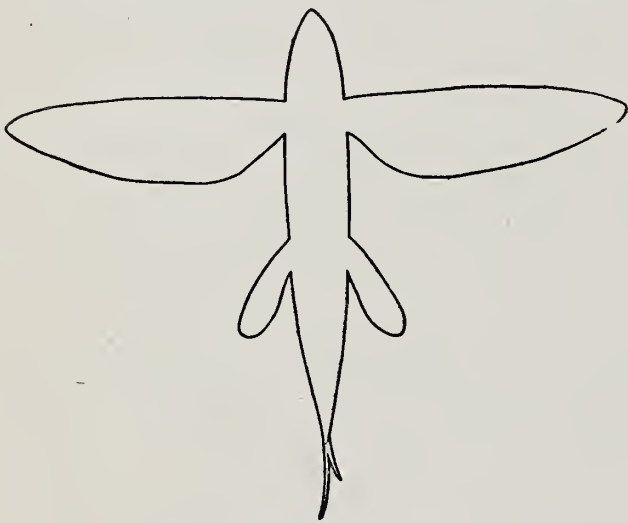


FIG. 74.
Outline of a flying-fish.

at high speed. No proof exists that their speed in such cases is less than it would be if they were crossing wave crests at right angles. I will now pass on to my own observations. Fig. 74 represents the outline of a flying-fish of $14\frac{1}{2}$ in. length and 17 in. span

that I obtained from the Naples Marine Biological Laboratory. In the figure I have shown the hind wings pointing outward and backward. In actual flight the hind wings appear to be directed outward at right angles to the body. But they also appear to be placed further back than they are in the actual specimen. I suspect that in reality the hind wings are directed as in my figure, but that in flight only the hinder parts of the wings were visible. The hind wings of my spirit specimen could not be placed at right angles with the length of the body without considerable force and without raising the scales at the base in a way that is not likely to happen in life.

In fig. 75 is shown a transverse section of this flying-fish showing the apparent range of movement of the fore wing in flapping flight based on my own observations. From this figure it is clear that the observed range of movement is far greater than is likely to be caused by vibration of the body produced by beats of the tail or action of the air.

FIG. 75.

Transverse section of a flying-fish, showing range of beat of wings.



In fig. 76 I show certain of the muscles that move the wings. Just behind the gills I found the muscle that advances the wing. This is shown at A. It may be noted that it is attached to the base of the first fin-

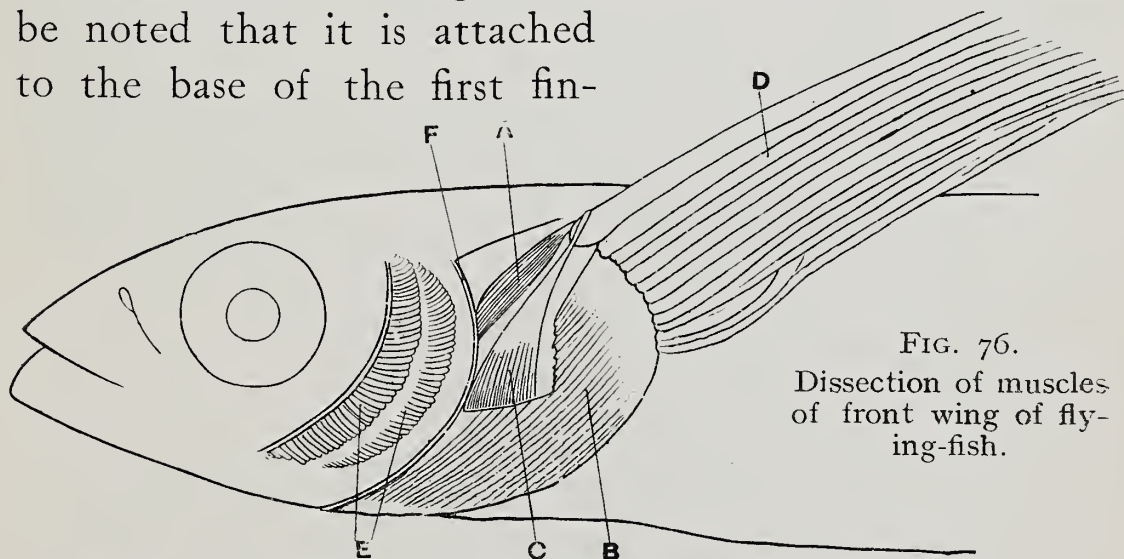


FIG. 76.

Dissection of muscles of front wing of flying-fish.

- | | |
|---|--|
| <p>A. Muscle for advancing the wing.</p> <p>B. Superficial muscle for pulling wing downwards.</p> <p>C. Muscle for producing camber. (This has been exposed by cutting away part of B.)</p> | <p>D. Rays of folded wing.</p> <p>E. Gills exposed by cutting away gill cover or operculum.</p> <p>F. Shoulder girdle.</p> |
|---|--|

ray. It only acts directly on this first fin-ray. When it pulls this forward, the other rays have to follow, as they are attached to this ray by the membrane of the wing. Immediately beneath the skin is a large flat

muscle B that pulls down and aids in advancing the wing. This, however, does not pull down the first fin-ray. On the dorsal side are two muscles for raising the wing. The hindmost of these appears also to act in retiring the wing. These two muscles are attached chiefly to the middle of the wing. That is to say, they do not appreciably affect the first one or two fin-rays.

From this description it follows that when the wings are dihedrally-up they must be cambered. On the other hand, when they are flat, or dihedrally-down, it is likely that camber is diminished or abolished.

On cutting away part of the muscle B, I found a deeply situated muscle, shown at C, that has the power of pulling downwards the first and, to a lesser degree, the second fin-rays. Thus the action of this muscle must be to increase the camber of the wings. Its tendon is attached to the front and upper surface of the first fin-ray. Therefore it not only pulls this ray down but also tends to rotate it thus further increasing the camber.¹

I have elsewhere described the different mechanisms for changing camber employed by birds and bats. It is interesting to find that a mechanism of quite a different nature is at the disposal of the flying-fish. That this mechanism is used in steering from side to side is suggested by the following observation :

22nd February, 1912, in the Arabian Sea. At 1.45.—A large flying-fish seemed to make a slight steering movement to keep it on its course. The inside wing appeared to be suddenly jerked, and I formed the impression that its anterior margin was slightly rotated downwards as if to increase camber. It is easier to believe that this happened than to believe that I saw it happen.

¹ This camber muscle is developed from the first of a series of deep-lying muscles that pull down the wing. A homologous muscle is present in the hind wing. Dr. Nicholls and I failed to find that it had any power of affecting camber. It seemed to act more in advancing the fin. But whether or not the hind wing has a camber changing mechanism can only be finally settled by dissection of fresh specimens. In spirit-hardened specimens the action of the muscles is less easy to discover.

The scepticism that I thus expressed in my notes written at the time did not prevent me from afterwards carrying out the necessary dissection to see whether a camber-changing mechanism existed.

As some observers have doubted whether flying-fishes can steer from side to side, it will be of interest to quote some observations that prove that they do steer in this way :

22nd December, 1911, near middle of Red Sea. At 4.48 p.m.—A flock of small flying-fishes flew up-wind for about one metre at starting. They then simultaneously steered off wind through an angle of about 90° , and remained flying for four seconds.

21st February, 1912, in Arabian Sea. At 7.12 a.m.—A flying-fish gliding up-wind. It steered through a right angle so that it travelled with wind abeam.

22nd February, 1912. At 2.50.—A flying-fish started with the wind abeam. It steered up into the wind and off on the other tack by nearly a right angle—that is to say, while describing a sharply curved course, it steered through about 160° .

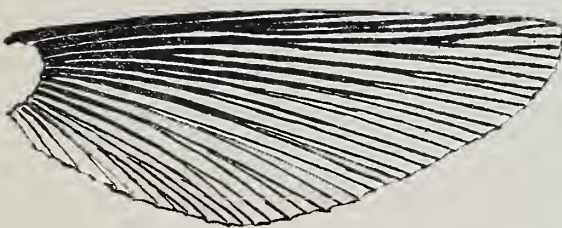


FIG. 77.
Wing of a flying-fish.

In fig. 77 is shown the wing of a flying-fish. The upper surface of the wing is smooth. But the fin-rays stand out prominently on the under surface forming sharp ridges. Most

of them, as shown in the illustration, are branched peripherally. One would expect that these ridges would interfere with the gliding motion through the air. The wing of such an extraordinarily efficient glider as the flying-fish is the last place where one would expect to find such a defect, if it be a defect. In figs. 78B and 79B is shown a transverse section through one of the digital quill feathers of an owl. When the wing is in use this feather is extended at right angles to the line of flight. The vane of the feather is so arranged

that the mid-rib or shaft does not stand out appreciably either above or below. That is to say there is no outstanding ridge on the feather that might interfere with



FIG. 78.

Transverse sections of digital quills of an adjutant (A) and of an owl (B).

gliding movement through the air. In figs. 78A and 79A is shown a section through a digital quill feather of an adjutant bird. In this case the mid-rib stands out prominently on the under surface of the feather. A similar feature is found in the digital quills of other

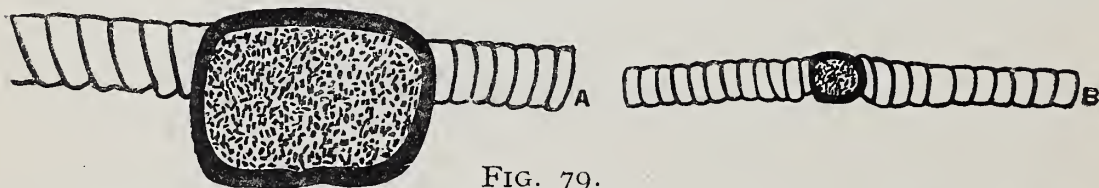


FIG. 79.

Transverse sections of central parts of digital quills of an adjutant (A) and an owl (B) magnified. In the case of the adjutant, the shaft stands out strongly on the under surface of the feather. In the case of the owl, owing to the thickening of the web on either side of the shaft, the latter is slightly recessed.

soaring birds. It is interesting to find that, in the presence of ridges standing out transversely to the line of flight, the wing of the flying-fish differs from that of the owl, and resembles the wings of those birds that get energy from the air for soaring flight.¹

¹ In the larger owls the shaft of the digital quills is nearly or quite level with the vane of the feather, at least of that part that is not overlapped by neighbouring feathers. I have observed this in *Syrnium newarensense*, *Syrnium collatus*, *Syrnium nivicola*, *Syrnium bidduphi*, *Syrnium indrani*, *Ketupa zeylonensis*, *Bubo bengalensis*, *Bubo coromandus*, *Glaucidium cuculoides*, *Ninox scutulata*. In all these species the under surface of the feather has a high degree of polish, in strong contrast to the rough dull surface of corresponding feathers of soaring birds. On the other hand, in certain of the smaller owls, the shafts, so far as I could see, stand out to some extent. This appears to be the case in *Strix flammea*, *Asio acapitrinus*, *Glaucidium radiatum*, *Athene brama*, *Scops spilocephalus*, *Scops giu*, and *Scops bakkamoena*. In these cases the under surface of the feathers is not polished, or only polished to a slight extent. It often happens that, owing to its lighter colouring, the shaft appears to stand out when it does not do so in reality. The only way to be certain is to cut a transverse section of the feather, and to examine it with the help of a lens. Besides, in the more common soaring birds the shaft stands out on the under side of the digital quills in *Gypætus barbatus*, *Milvus melanitis*, *Pernis cristatus*, *Aquila chrysaetos* and *Aquila hastata*. In *Aquila vindiiana*, on the other hand, the shafts stand out but slightly and the under surface of the feathers is somewhat polished. In the swift the shafts of the digital quills stand out on both surfaces, of the vane of the feather. It is significant to find this feature in the wing of a bird that may be described as specialised for high speed flight in soarable air, in view of the heights to which it commonly attains.

I have now to describe the flight of flying-fishes in a smooth sea, with the surface either glassy or only disturbed by slight ripples. The observations that I am about to quote commenced on the 16th February, 1912, by which date my eye had become sufficiently practised for me to be able to see with certainty whether the wings were at rest or in motion. My observations were mostly carried out with the help of a binocular:

16th February, 1912, in Red Sea. At 11.51.—Sea glassy. A flying-fish seen to drop tail before plunging. This only occurred near the end of its flight. While gliding, the sun was seen reflected from the wings. The shine was constant, not flickering. Therefore, the wings were not flapping.

12.27.—In wind patch. Ripples (less than half an inch high) were in two directions. Of these Series I. were curved short ripples. Series II. were longer straight ripples. (Ripples of Series II. generally make an angle of about 45° with ripples of Series I.) Ripples of Series I. suggested that the wind was ahead. A flying-fish, while gliding, showed slight lateral instability.

12.36.—A flying-fish seen gliding beam on to a slight head wind. Its wings were clearly seen to be still.

During the morning of this day no longer flight was timed than eight seconds. There was bright sunshine. During the afternoon cirrus cloud was gradually increasing over the sun, and patches of wind ripples became less frequent. Usually the sea was smooth, with a glassy surface, as far as the eye could reach. Under these conditions exceptionally long flights were timed:

3.14.—Sea glassy all over except far astern. Glides of 9 and 18 seconds timed by Somerset.

3.26.—A flying-fish seen to lower tail, and raise it again. The speed seemed to have increased when the tail had been raised. In the raised position the hind fins were still below the level of the front wings.

3.33.—Slight cirrus clouds over sun. A flying-fish seen to lower tail into the water four times during a glide. Each time, as soon as it reached the water, the tail was wagged energetically to and fro. The tail remained in the water while the animal glided for about 2 metres.

3.35.—A flying-fish twice lowered its tail into the water during a glide. Just before plunging, it somewhat slowly lowered its tail. It was up for 7 seconds.

4.55.—Somerset and I watched a flying-fish glide for 20 seconds. During this flight it touched the water with its tail seven times, and during the middle of the glide for about a second it seemed to flap. This was a naked eye observation.

5.17.—Somerset timed and I watched a flying-fish glide, on a slightly curved course, for 24 seconds. The light was bad, and it is doubtful how often the tail touched the water. I saw it do so twice. I thought I saw flapping for a second during the middle of the glide. There were slight ripples from the east.

5.19 to 5.40.—Flights timed of 9, 10, 9, 4, 9, 7, 7, and 11 seconds, with 4, 5, 0, 1, 1, 1, and 5 tail touches.

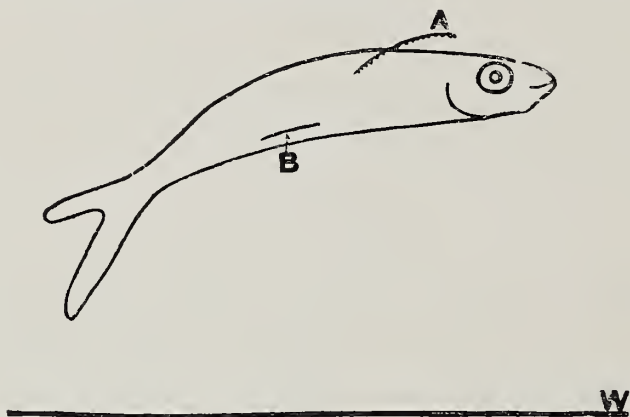


FIG. 80.

Flying-fish seen from the side gliding in unsoarable air. Wings cambered and dihedrally-up.

W. Water level. A. Fore wing. B. Hind wing.

Similar observations were made in the Arabian Sea in equally fine weather :

20th February. 12.35.—Stronger ripples of Series I. only, and confused, forming small waves. A flying-fish, whose wings appeared black, made a long flight. Wings were still. There were slow lateral oscillations. The direction of glide was nearly directly to leeward.

2.1.—Over glassy sea a flying-fish made a long glide with one tail touch. Its wings appeared black. It showed slight lateral oscillations. Tail-wagging and increase of speed seen during the touch.

2.5.—A flying-fish in the middle of a long glide seen to flap wings for about a quarter of a second. It also made one tail touch, apart from the flapping. The sea was nearly glassy.

3.0.—Sea glassy. Bright sunshine. Flying-fish seen to flap wings after starting when 3in. or 4in. up. Then, after travelling some distance, it put tail in water, and wagged it, flapping the wings at the same time. It appeared to lose speed before finally plunging into the water. But no dropping of the tail to cause this could be seen.

While thus flying in calm air the wings are dihedrally-up. As previously explained there is little doubt that

they are cambered while in this position. The tail hangs down, whether or not it reaches the water, as shown in fig. 80. Their speed under these conditions is low. I doubt whether it reaches ten metres per second. The source of energy of their flight is to be found chiefly in the wagging movements of the tail while the caudal fin is immersed. This sculling action produces small ripples which are visible at the end of each to and fro stroke. Hence the fish is seen to be followed by a double line of disturbance or wake on the water.

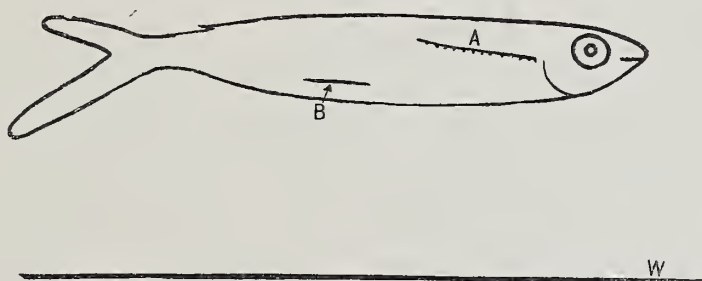


FIG. 81.

Flying-fish seen from the side gliding in a soarable wind at high speed. Wings flat or slightly dihedrally-down. Angle of incidence possibly negative. No camber.

W. Water level. A. Fore wing. B. Hind wing.

In rare cases, besides the tail wagging, further propulsive action is caused by flapping the wings. It is probable, but not certain, that exceptionally long flights mentioned by a few observers have been flights in which at intervals the tail was lowered into the water and used as a propeller. It is not necessary to assume that movements of the tail could give the animal a speed of ten metres per second while its body is immersed in the water. The speed increases rapidly to gliding speed when the body has emerged and while the tail is still immersed.

Thus over a glassy sea, and at any rate when the sunshine is diminished by cirrus cloud, no other sources

of energy for the flight of the flying-fish need be looked for or assumed than those above described.

The following observations describe the flight of flying-fishes in a strong and probably soarable wind :

22nd February, 1912, in Arabian Sea.—Wind north. Strength up to 5 on Beaufort scale (19 to 24 miles per hour). Temperature, 78°. White tips to waves, and spray occasionally blowing on board.

6.20.—A flying-fish seen to flap for about 8 metres at starting. It then glided, becoming canted while so doing, and plunged into the water after a short flight.

7.7.—A flying-fish during a short flight touched water, and while so doing fluttered wings, and wagged tail.

8.0.—A flying-fish seen gliding. Its wings were still, and tail was not hanging down.

8.9.—A flying-fish seen gliding in same direction as the ship. Its tail was certainly horizontal (fig. 81). Also a sudden tilt up of the tail was seen. This was a sudden rotation of the fish round its transverse axis. The tail returned back to its original position immediately, and the fish then plunged into the water.

8.17.—In two cases tail touched water during a flight, and at the same time the wings were flapped.

8.20.—A flying-fish at starting seen to have tail hanging down. It was travelling in direction of ship. Then the body became horizontal (*i.e.*, tail lifted) during the remainder of the flight. Immediately afterwards a similar change of tail position was seen in another flying-fish.

8.26.—A flying-fish seen with tail horizontal. The wings were clearly seen to be still. This was a short flight.

10.22.—No spray coming on board. Wind probably less. A large flying-fish seen to keep tail down while gliding. This was seen during almost the whole of the flight. It was a long flight up-wind.

10.32.—A flying-fish during a squall seen to flutter wings much at starting.

10.54.—A flying-fish seen gliding. Wings appeared purplish grey. They were not dihedrally-up. They appeared to be either flat or slightly dihedrally-down. The pelvic fins seen. They were flat.

11.37.—Spray coming on board.

11.43.—A flying-fish gliding. Its tail was up. The wings appeared black, and slightly dihedrally-up. This was a long flight.

12.0 to 12.15.—Several flying-fishes seen near. I failed in each case to find them with my binocular. This was probably due to fatigue, as, on making a sudden aim for the horizon, I also missed.

12.30 to 12.50.—Several flying-fishes seen. Their wings looked grey and indistinct. I suggest that this appearance was due to fatigue.

5.0.—Wind and sea were less. A flying-fish with wings slightly dihedrally-up seen to make three tail touches during a flight. It wagged tail each time of touching. The wings were seen to be still. They appeared of dark colour.

5.12.—Waves less, but surface black from a squall. A flock started. Two were watched. Their wings were seen to be still and flat. The tail in each case was up. The wings appeared bluish.

5.15.—Wind less. A large flying-fish seen. Its wings appeared black. They were dihedrally-up, and the tail was down. The wings were still.

5.32.—A flying-fish seen to tail-wag at starting. Its wings were slightly dihedrally-up. It made a sharp turn round its transverse axis while passing over the top of a wave.

An interesting and also a conspicuous feature of flight in a strong wind has not been mentioned in the above notes. It is that the speed over the water was much greater than is observed in calm weather flight. My observations were mostly made on the windward side of the ship. The flying-fishes either started head to wind, or if they started in a different direction they usually steered so as to travel away from the ship in an up-wind direction. In calm or nearly calm air the observed speed is perhaps ten metres per second. They start when frightened as proved by the fact that in whatever direction they start they nearly always steer so as to go away from the ship. Being frightened they must in most cases at least use the highest speed attainable under the circumstances. But in the disturbed weather flight above described their speed over the water must have been much greater. It may have been about fifteen to twenty metres per second. This high speed added greatly to the difficulties of observation. In a calm the speed through the air must be equal, or nearly equal, to the speed over the water. But in a wind, as especially in squalls as above cited, the speed through the air must differ widely from the speed over the water.

It is likely that the speed through the air observed by me amounted to over thirty metres per second. The distances covered appeared to be of the same order of

magnitude as I have seen in calm air. But I have been told that, in the Arabian Sea during the monsoon, flying-fishes are frequently seen flying for much greater distances than are observed in fine weather.

Thus the evidence shows that the unaided exertions of the flying-fish can give it a speed of ten metres per second or thereabouts. During a squall it shows a speed of three times as much. Therefore, in this latter case, there must be some extraneous source of energy.

The source of energy cannot be that the flying-fish has skill in finding ascending currents and in avoiding descending currents because its course is often a straight line. The source of energy cannot be that it meets ascending currents reflected up on the windward side of each wave for if this were the case it would only show high speed if it crested a succession of waves. As a matter of fact more often than not it starts in the trough of a wave and always appears to be travelling at high speed the moment it has completely emerged from the water. It may travel at high speed for a long distance in the trough of a wave. There is no evidence of any difference of speed should it cross over wave crests or fly on their windward side.

Thus it is obvious that the flying-fish must be getting energy from the air. If it does so by means of ascending currents these currents must be so tightly packed that the animal has no need to turn out of its way to look for them. Further, these currents can have nothing to do with the ascending currents on the windward side of each wave. Just as in the case of fast flex-gliding birds every minute portion of air appears to be as ready as any other minute portion to furnish energy for the flight of the flying-fish.

The slow-speed flight in a calm, with wings dihedrally-up and cambered, and the tail touching the water with sculling motion at intervals, may be compared with the flap-gliding flight of soaring birds.

Medium-speed flight in a moderate wind, with wings dihedrally-up and cambered, tail hanging down but clear of the water, and occasional evidence of lateral instability, may be compared with circling or lift-gliding.

High-speed flight, with wings flat and not cambered, with angle of incidence possibly and probably negative, and with tail up (fig. 81), may be compared with flex-gliding. Flex-gliding of birds is often accompanied by evidence of transverse axis instability. This form of instability is, as will be shown later, usually associated with a high degree of soarability and frequently also appears to be associated with the presence of soarable wind. It is of interest that the above observations include one reference to transverse axis instability in a flying-fish and that this occurred in high-speed flight.

It is not necessary or advisable to apply the term soaring flight to the gliding of a flying-fish. But the facts show that it obtains energy from the air in the same unknown way as does the soaring bird. One difference between the soaring flight of birds as hitherto described and the flight of the flying fish is that, in the latter case, air energy is only available in the presence of wind. In sun soarability wind is of no importance for the soaring flight of birds. But in later chapters I am about to bring forward definite proofs that wind is necessary for "wind soarability," which is another form of soaring flight observed in Agra. It is of interest that in the case of flying-fishes air energy was especially available in the presence of squalls. In Chapter XVII.

I shall bring forward evidence that in some cases air during gusts is more ready to furnish energy for wind soarability than is the air between the gusts in respect of the flight of birds, and I shall also show that in certain cases transverse axis instability is only observed during gusts.

The reader will readily infer from the above quoted extracts from my diary that while observing I was not conscious of any idea of the bearing and meaning of what I saw. Had the converse been the case I should certainly have attempted to see whether or not the angle of incidence is negative in high-speed flight. I commend this point to the attention of other observers.

CHAPTER XIV.

THE FLIGHT OF SEAGULLS.

In earlier chapters it has been proved that sun energy can be stored in the air and become available for soaring flight. No evidence of a positive nature has yet been brought forward as to the nature of the mechanism by means of which energy is stored and becomes available for doing mechanical work. In Agra, in "sun soarability," the stored energy can be used for soaring in the absence of wind properly so-called. In the case of flying-fishes on the other hand air energy was only available for aiding their flight in the presence of a considerable amount of wind. This is the first case we have dealt with of "wind soarability."

In complete or nearly complete absence of wind in the Red Sea flying-fishes showed no sign of the use of air energy as occurs in soaring flight. The amount of sunshine present would, in Agra, have inevitably produced a high degree of soarability. Presumably the energy available in the presence of wind is ultimately derived from sun energy. It is curious that in one case wind is unnecessary and in the other case necessary for this energy to be available for soaring flight. I now propose to bring forward further evidence of the conditions under which air energy is available for soaring flight at sea. The few observations I am about to quote will be found rather of interest in suggesting lines of investigation than in leading to any definite conclusion. The two observations on the following page suggest that there is some difference in the nature of the soarability present at sea and inland.

18th February, 1912.—Arrived at Aden at mid-day. Bright sunshine and light S.E. wind. Cheels and gulls circling, but mostly taking advantage of ascending currents. No flex-gliding.

25th February, 1912.—At Jhansi station on G.I.P. Railway. At mid-day. Cheels and scavengers circling and flex-gliding. They appeared to avoid the ascending current reflected upwards from the railway station. While I was watching them (for about ten minutes) only one cheel came into the area of this current. Bright sunshine. Light wind moving small branches.

That is to say in Aden Harbour surrounded by the sea in bright sunshine and at mid-day the soarability was not sufficient for the flex-gliding of cheels. On the other hand, at the inland town of Jhansi, which is of over 11° more northern latitude than Aden, the air was fully soarable. So far as I am aware in the presence of bright sunshine in any inland place in India and at mid-day the air is always fully suitable for soaring flight.

Whether or not sunshine produces the same effect at sea as at inland places it is a matter of common knowledge that there is one place at sea where the presence of soarability is frequently observed, namely, near the stern of a steamer when in motion. In describing gulls following a ship Maxim says: "In a calm or headwind we find them directly aft of the ship; if the wind is from the port side, they may always be found on the starboard quarter, and *vice versa*."

Lanchester, describing the same phenomenon, says: "In January, 1893, the author witnessed the spectacle of some twelve or fifteen herring-gulls following in the wake of the ss. *Germanic* the whole voyage from Liverpool to New York. The weather was stormy, and the passage occupied some ten days. In spite of this, the gulls followed without difficulty, soaring continuously day and night. The author watched these gulls sometimes for upwards of an hour, and scarcely a single flap amongst the whole flight could be observed."

That is to say, when the steamer is moving ahead, there is a "soarable area" near the stern in which gulls can glide without effort. As soon as they leave this soarable area they have to indulge in flapping flight. The obvious explanation is that there are ascending currents in the soarable area, caused by the motion of the ship, and of which the gulls take advantage. But the contents of preceding chapters have abundantly shown that in dealing with soaring flight it is not wise to accept "obvious explanations" without evidence. If the wind is on the port side ascending currents can be shown to exist on the port side by the simple expedient of letting loose small pieces of paper. These pieces of paper if let loose near the starboard quarter show no evidence of any constant ascending current in the soarable area. On the other hand pieces of paper tend in this area to lose height rather rapidly. I do not wish to deny that the soarable area may be due to ascending currents or some other effect on the air produced by the movement of the ship. But it is necessary, before coming to a conclusion to bring forward evidence consisting of facts of observation.¹

There is no doubt that the phenomena differ in different cases.² For instance, in the above-quoted

¹ On first seeing gulls following a ship in the "soarable area," it is very difficult not to believe that they are not aided in some way by staying in the mass of air being carried on by the ship, or by variations in wind velocity. When in the soarable area gulls are usually facing the wind more or less. If, as is thus suggested, they only gain height when wind-facing, this fact might be regarded as a proof that they are aided by variations in wind velocity (see Lanchester, "Aerodnetics," page 309). It is difficult to see how variations of wind velocity could explain flex-gliding flight inland, where the flight takes place in all directions relatively to the wind, and also at highest speed sometimes in the apparent absence of wind. Facts to be described in the following paragraphs will be found to prove that other factors besides variations in wind velocity must be involved.

² In *Nature* for 10th October, 1912, page 161, E. H. Hall states that gulls gliding after a ship keep to the windward side of the stern. F. W. Headley, in *Nature* for 24th October, 1912, page 220, states that they generally keep to windward. This is the converse to Maxim's and my own observations. So long as such contradictory statements are made as to the facts of the case, any dogmatic statement as to the explanation is out of place. In my experience the soarable area is on the leeward side. Gulls in this area may glide, from leeward, a little to windward of the middle line of the ship. But they appear always to take up a position to leeward of the probable area of influence of the ascending current reflected up on the windward side. There can be little doubt that the position of the gulls varies in different cases.

experience of Lanchester there was scarcely any flapping. This is not always the case in the soarable area. During a recent voyage from Marseilles to Bombay I noticed on more than one occasion that the gulls in the soarable area from time to time made one or two flaps of the wings. Immediately before this flapping there was a sudden rotation upwards round the transverse axis. If this tipping-up round the transverse axis had been gradual it would be reasonable to suppose that it was a voluntary adjustment employed as a preparation for flapping. But the suddenness of the movement makes it probable that it was due to a defect or irregularity in the air of the same nature as that that causes tail-jolting in cheels. That is to say it is probable that the flapping was intended to return the bird to its normal position in relation to its transverse axis.¹

Further, my observations make it probable that a soarable area can only be developed under certain atmospheric conditions. For instance :

9th February, 1912.—Left Marseilles on the P. and O. ss. *Arabia*. There had been bad weather the day before in the Gulf of Lions, and stormy weather had been reported from Gibraltar. It was now fairly calm. Owing to the war in Tripoli, lighthouses were supposed not to be burning in the Straits of Bonifacio or Messina. Hence the ship took the outside course, passing to the south of Sardinia and Sicily.

10th February. At 10.0 a.m.—Off the south of Sardinia. Glare. No sunshine. Light westerly wind (force 3 on Beaufort scale = 8 to 12 miles per hour). Temperature, 61°. Gulls gliding on port quarter with occasional flapping. Advancing of inside wing at moment of wing depression seen twice, apparently to check canting.

2.30.—Wind light, and nearly ahead. Gulls astern, all in flapping flight. They showed rise and fall of body between strokes. This had not been noticed earlier in the day. They remained energetically flapping after the ship for the next two hours. Slight sunshine.

4.30.—Wind from the starboard quarter, and strong. Gulls soaring without flapping in soarable area on port quarter.

¹ If this is the case one would expect flapping for this purpose to be carried out with the wings in the retired position. This is a point on which observation is required. I have seen the appearance of flapping with wings retired in a gull not near the soarable area, and noted that the appearance was possibly due to the flexing of the wings.

That is to say in a "disturbed-weather wind" there was a soarable area. Then came a period of two hours of "fine-weather wind" with no soarable area. Again soaring flight became possible when a fresh wind sprang up. The two hours without soaring cannot be due to the weakening of the wind as on other occasions I have seen a soarable area in equally light or lighter winds. The evidence now brought forward indicates that, besides the effect of the air disturbance caused by the motion of the ship, another factor of importance

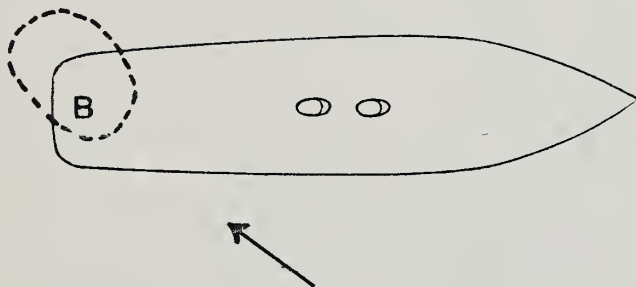


FIG. 82.

Plan of after part of a ship showing soarable area (as dotted line) on leeward side of stern. The arrow shows the wind direction.

is the nature of the wind. In Agra some winds are soarable and other winds are not soarable. Apparently in both cases some unknown factor affecting soarability is involved.

10th February. At 5.5 p.m.—Several gulls had stayed behind and settled on the sea, probably to eat some refuse. They started flapping after the ship. Each one as it reached the soarable area on the leeward side and near the sea level, turned through a right angle and glided upwards, without flapping and at high speed, to reach the usual position over the stern of the ship. The gain of height must have been about 6 metres. The angle at which they glided upwards must have been about 40° with the horizon. The gulls did not arrive all at once, but at intervals of a few seconds, proving that the conditions favourable for upward gliding were, at the time, permanent. When the gulls reached the position B in figs. 82 and 83, they remained gliding without apparent effort, except for an occasional flap.

In view of the fact that the gulls, as they reached the soarable area, turned sharply through a right angle and glided steeply upwards at apparently high speed,

the energy involved in their glide cannot be explained entirely by their original speed ahead due to flapping. They must have been taking energy from the air. If this energy is available owing to ascending currents or other movements of parts of the air these movements must be sufficient to enable a gull to glide upwards at an angle of about 40° with the horizon.

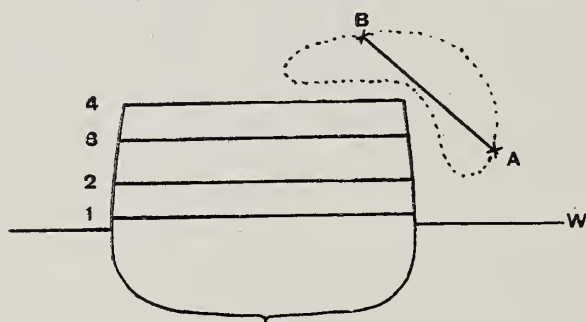


FIG. 83.

Section of a ship near stern showing soarable area (as dotted outline). WW. Water level. The line A B shows direction in which gulls were seen gliding upwards without flapping in soarable area. 1. Main deck. 2. Spar deck. 3. Hurricane deck. 4. Boat deck.

12th February.—Wind force, 0 to 2. Quite fine. At mid-day two gulls arrived, and after two minutes' flapping near the ship were left behind.

13th February.—A following wind (W.S.W. to W.N.W., strength 2 to 5 = 4 to 24 miles per hour). The wind was often faster than the speed of the ship. A group of fifty gulls remained near the stern all day. They were always in flapping flight. They carefully avoided the ascending current that must have existed at the stern when the wind velocity was greater than the speed of the ship. This was especially noticeable in the case of a gull that had a piece of food in its mouth, and that was being chased by three others. It turned in all directions for several minutes, but never once came into this ascending current.

4.7.—Wind W.N.W. Force 4 = 13 to 18 miles per hour. The speed of the ship was checked to take up a pilot outside Port Said. The ship slowly turned towards the south, so that the wind was abeam. The gulls began gliding in the ascending current then produced on the windward side without flapping. When thus wind-facing they reached a height of probably 100 metres above the ship, and a position of 80 metres to windward.

That is to say in one case the gulls took advantage of an ascending current ; in the other case they avoided it. Similarly in *Agra* cheels and scavengers take advantage of ascending currents when the wind is not

soarable. But when the wind is soarable they take care to avoid such currents. The reason for this avoidance is suggested by the following two observations:

21st May, 1912, at House. At 3.45.—Dust storm. Slightly yellow. Heavy cloud about.

4.20.—Storm continuing. Dust now grey. Wind north.

4.30.—A young scavenger vulture gliding towards the west. Wind north-west. Its wings were flat and even. There were occasional slight relaxations of secondaries. It glided over the corner of the house at a height of about 5 metres. As it reached the ascending current reflected up from the house, it showed the emergency adjustment, dropping legs and flexing wings. Its instability, as it glided on beyond the ascending current, consisted of sudden lateral oscillations and sudden single-wing depressions. It occasionally showed tail-jolting.

23rd May, 1912. At 3.1 p.m.—A dust-storm, in which instability shown by birds was less than usual.

3.38.—A dusty wind, moving branches. Fort dimly visible. Cheels gliding up-wind showed occasional slight single-wing depressions and tail-jolting. A cheel came near the ascending current reflected up from the house. It immediately showed strong double dips (*i.e.*, transverse axis instability) and single-wing depressions (*i.e.*, dorso-ventral axis instability).

On the other hand it is a fact that if the wind is unsoarable when a bird glides from leeward into the ascending current, reflected up from the Fort battlements for example, it shows scarcely any instability. That is to say it is probable that birds avoid ascending currents in soarable air because such air when reflected upwards, causes a high degree of instability.

On the day following the last-quoted entry in my diary the ship left Port Said and entered the Suez Canal. It is interesting to observe the change from sea soarability, under the influence of disturbed weather in the Mediterranean, to fine weather and inland soarability along the Canal.

14th February, in Port Said. At 7.0 a.m.—Wind force 4 = 13 to 18 miles an hour. Wind direction, N.W. Stormy sky. Cloud over sun. Gulls circling or leelooping at 200 metres height. In leelooping, when turning round to face the wind, they showed an apparently vertical gain of height. Double dips seen at end of windward side of circle. Gulls at low levels in flapping flight only.

8.0.—Leaving Port Said and entering Canal. Wind force as before. Temperature, 57°. There was a small soarable area on the leeward quarter reaching up to the hurricane deck level only. Each gull on reaching this soarable area glided, and showed a gain of height of a metre or more. In making this gain of height they glided upwards at an angle of about 30° with the horizon. No gulls on windward side of ship.

8.50.—Wind much less. A few gulls following the ship all in flapping flight. No soarable area.

9.0.—A number of pelicans starting. They formed line of quarter column. The line undulated. The birds flapped at the tops of the undulations. Sunshine. Cold.

11.0.—Wind variable, up to strength 1 = 1 to 3 miles an hour. Sunshine. Gulls occasionally circling and gaining height up to about 300 metres. No gliding in a straight line without loss of height, except in cases of gliding up-wind in ascending currents reflected up from steep banks, etc.

2.0.—Thin cirrus cloud. Light wind. A hawk circling with wings dihedrally-up. It showed much lateral instability.

2.5.—A scavenger seen at 300 metres slow flex-gliding. Gulls at a height were circling and fast flex-gliding without loss of height.

On the following day at sea in fine weather the phenomena of sea soarability, *i.e.* a soarable area near the stern, were again observed :

15th February. At 8.0 a.m.—Leaving Gulf of Suez. Wind S.S.E.—that is to say, nearly directly ahead. Force 2 = 4 to 7 miles an hour. Temperature, 66°. The soarable area reached up to the level of the hurricane deck only. Gulls near the limit of the soarable area were making flaps of small amplitude. Thin cirrus over sun. Five gulls were in the soarable area. Occasionally one or two flaps followed a sudden tip up round the transverse axis.

8.12.—The ship reached a patch of calm. The sea had a glassy surface. The gulls remained behind, and settled on the water.

It may be noticed that the fact of the soarable area only reaching up to the hurricane deck level in the Canal cannot be due to the low speed of the ship as the same phenomenon was also noticed near the mouth of the Gulf of Suez when the ship was proceeding at full speed.

The above description of gulls in a limited soarable area near the stern of a ship does not exhaust the facts of soaring flight at sea. The albatross appears to be less restricted in its flight. J. A. Froude, quoted by Lanchester, gives the following account : The albatross

wheels in circles round and round and for ever round the ship — now far behind, now sweeping past in a long rapid curve, like a perfect skater on an untouched field of ice. There is no effort. Watch as closely as you will, you rarely or never see a stroke of the mighty pinion. The flight is generally near the water, often close to it. You lose sight of the bird as he disappears in the hollow between the waves, and catch him again as he rises over the crest ; but how he rises and whence comes the propelling force is, to the eye, inexplicable ; he alters merely the angle at which his wings are inclined ; usually they are parallel to the water and horizontal, but when he turns to ascend, or makes a change in his direction, the wings then point to an angle, one to the sky, the other to the water.”

Moseley,¹ in describing the flight of the albatross, gives a somewhat different description : “ I believe that albatrosses move their wings much oftener than is suspected. They often have the appearance of soaring for long periods after a ship without flapping their wings at all ; but if they be very closely watched, very short but extremely quick motions of the wings may be detected. The appearance is rather as if the body of the bird dropped a short distance and rose again.² The movements cannot be seen at all unless the bird is exactly on a level with the eye. A very quick stroke, carried even through a very short arc, can, of course, supply a large store of fresh momentum. In perfectly calm weather albatrosses flap heavily.”

¹ See Moseley “ Notes by a Naturalist on the Challenger ” (Macmillan and Co., London), pages 134 and 570.

² It is possible that this movement was due to transverse axis instability. This might be cleared up by further study of the flight of the albatross. The suggestion that soaring flight in general is due to undiscovered movements of the bird is negatived by (1) the fact of soaring flight starting at a definite time of the day—there can be no reason why a bird could make such movements after but not before a particular time ; (2) by the complicated relation of cloud shadow to soarability ; and (3) by the constant position of the wing-tip feathers in fast flex-gliding.

The interesting point in the above description is that albatrosses flap in perfectly calm weather. Apparently if there is a wind then a soarable area exists near the stern of a ship if not elsewhere; while if there is a calm the movement of the ship is incapable of rendering the air at the stern suitable for soaring flight. In an observation described above gulls left the stern of the ship as soon as a patch of sea with glassy surface was reached. The facts brought forward are obviously insufficient to justify a conclusion, but whether or not a soarable area exists in complete absence of wind is a point well worth the attention of other observers, although perhaps this suggested conclusion may be described as *a priori* improbable.

Moseley states that "at Tristan da Cunha the albatross nests actually within the crater of the terminal cone around the lake, 7,000ft. or more above the sea." The albatross is not likely to flap up to this height any more than to walk there, and it would be interesting to know whether it can only attain this height by circling up in a wind on the windward side of the mountain.

Some years ago I was on a steamer entering Aden. The speed was low, about eight knots. There was a light breeze making small ripples on the water. A gull approached the ship low down at the stern. It glided along parallel to the ship gaining height. It reached the level of the top mast when it was near the bows of the vessel. It made this large gain of height with its wings slightly flexed, as usual in gulls, and without a single flap. Its speed was such that I could nearly keep up with it when walking on the deck. Having reached the level of the top of the foremast it turned

away and when at a distance from the ship was seen to be in flapping flight. Captain Palmer, R.N.R., of the P. and O. ss. *Arabia*, tells me that in leaving Bombay, when the ship has a speed of sixteen knots, and with a headwind of perhaps five knots, he has often observed gulls gliding ahead parallel to the ship, and keeping at the same speed for minutes together. Sometimes they kept at a distance of only a few feet from the bridge and so under the best possible conditions for observation, and yet no trace of any movement of the wings could be observed. When leaving Bombay on December 16th, 1911, for Marseilles I witnessed a similar phenomenon. Gulls were noticed gliding at the same speed as the ship, and on a parallel course, and at a distance from me of only a few feet. I was standing on the hurricane deck. No trace of propelling movement could be observed. But I was able to notice that the wings often showed the digital quill gap, an adjustment discovered, in the case of gulls, by Mr. Howard Short, and recognised by him as being used to check speed. Were these cases of the soarable area being greatly extended, or was the air uniformly soarable under the tropical sun?

Besides the use of the digital quill gap for checking speed Mr. Howard Short has discovered that the small feathers on the back of the wing, known as coverts that cover the bases of the secondary quills, may be seen to be raised when speed is checked. My own observations, made at Aden, confirm this discovery. At Aden I renewed my acquaintance with the Indian cheel whose graceful flight was in strong contrast to the comparatively clumsy movements of the gulls.

18th February, arrived at Aden at midday. At 3.30.—The ship was slowly turned round, preparatory for starting, by means of a tug pulling at a hawser attached to the stern. As the ship turned, the wind was broadside on. Many gulls of different species and one or two cheels arrived and took advantage of the ascending current thus caused. They occasionally descended to the water to eat pieces of food that had been thrown overboard. Lifting of the tertiaries seen in a cheel at the moment that it increased its angle of incidence. The digital quill gap was often seen in gulls when gliding away from the wind, especially when the wind was not exactly broadside on to the ship. Lifting of tertiaries and coverts often seen in gulls on checking speed by sudden increase of the angle of incidence. Gulls often glided downwards with wings strongly flexed (= shoulder descent). Then when near the water they suddenly rotated round the transverse axis to check speed. While thus gliding with increased angle of incidence, the upper coverts over the secondaries often lifted, and were seen to be in flickering motion—that is to say, the lifting was not due to increase of camber bringing the secondaries away from the coverts. It must have been due to eddy currents formed over the back of the wing.

5.0.—Just outside Aden. A small soarable area astern. The wind was ahead and light. A gull gliding in this area showed digital quill gap on extending wings to check speed.

CHAPTER XV.

ASCENDING CURRENTS CAUSED BY THE HEAT OF THE SUN'S RAYS.

In previous chapters it has been shown that the sun is the source of the energy of ordinary soarability. We have now to consider the question whether soarability is due to ascending currents of air caused by the heat of the sun.

On a hot day distant objects may appear to be in tremulous shimmering movement owing to the rising of masses of heated air. This effect is well known on rifle ranges in India, where it is referred to as "mirage," and is known to interfere with shooting as soon as the sun gets warm. It is also known that this shimmering appearance is more easily seen through a binocular than with the naked eye.

In investigating these "heat eddies" I found that it is preferable for the binocular to be held firmly on a stand by means of a clamp. It is advisable to direct the binocular to some horizontal white line on a building at some distance away. The object looked at should occupy the centre of the field of view. While looking at the object the head must be held steady. The slightest movement of the head or of the instrument greatly adds to the difficulty of seeing heat eddies, especially at the time of their commencement in the early morning.

In order to find out whether one phenomenon is the cause of another it is necessary to be able to measure both of the phenomena. Then it is possible

to see whether a variation of one is followed by a variation of the other. Therefore, in order to determine whether heat eddies are the cause of soarability it is necessary to have some means of measuring these two phenomena.

The only measure of soarability available is the behaviour of cheels. In my later observations I found it advisable to observe cheels over the city rather than over the cantonment. Usually, but not always, cheels begin circling over the houses of the city a few minutes before they start over the trees and gardens of the cantonment.

A method of measuring heat eddies to some extent was furnished by the fact that they always develop in a certain order on different buildings in or near the Agra Fort when viewed from the roof of my house.

Supposing the weather is perfectly fine and undisturbed, and supposing the conditions are fully suitable for observation, the following is the sequence of events:

1. Heat eddies appear on the edge of the roof of a small shed situated on a level with the base of the Fort walls (as seen from my house). The shed is situated a few hundred yards from the Fort.

2. From two minutes to a quarter of an hour after the appearance of the shed eddies heat eddies may be seen to commence on the top of the wall of a small cemetery that is situated near the shed. The cemetery is on slightly higher ground than the shed but the top of its wall is on a slightly lower level than the edge of the roof of the shed.

3. The next building to show eddies is the outer lower wall of the Fort (near the Umar Singh Gate). These eddies are usually difficult to see and I have not often entered the time of their appearance in my notes.

There is usually an interval of several minutes between the cemetery eddies and the lower battlement eddies.

4. A few minutes later the wall of the bastion near the Umar Singh Gate appears distorted. The appearance is as if one was looking at a picture painted on a loose canvas and as if some one was pushing the canvas to and fro.

5. The level of the distortion of the bastion slowly rises and a few minutes later eddies appear on the top of the bastion.

About the time that eddies appear on the lower wall or battlements, eddies also commence on a barrack building in the Fort. This building is in a straight line beyond the top of the Umar Singh Gate bastion. Eddies only appear on the bastion when they have reached a certain intensity on the barrack.

As a rule at the moment that heat eddies appear on this particular bastion in the Fort the air becomes soarable. Supposing there is no wind, then as a rule, not a single cheel will have been visible before the appearance of the bastion eddies. Within a minute of these eddies developing eight or ten cheels may be seen circling over different parts of the city. In rare cases there may be a delay of several minutes between the development of bastion eddies and the development of soarability. On four or five occasions while watching cheels circling at the beginning of soarability I noticed that their flight changed from circling to flap-circling. On each of these occasions, on turning my binocular from the city back to the bastion in the Fort (a mile or two away), I found that its eddies had ceased. When a few minutes later its eddies recommenced soarability again commenced in the air over the city.

In the presence of wind, occasionally, local or temporary soarability may be observed before the appearance of heat eddies on the bastion.

Thus in perfectly fine weather, and in nearly every month of the year, it is possible for me by means of my binocular to find out whether or not the air is soarable and if the air is not soarable to make a guess as to how soon the change to soarability will occur.

The following are examples of my observations :

April 19th, 1910. At 7.52.—Heat eddies visible on shed.

8.19.—Heat eddies visible on cemetery.

8.40.—No cheels up.

8.42.—Heat eddies on lower battlements.

8.43.—Heat eddies visible on bastion.

8.45.—Cheels circling in city and near. Dihedrally-up position of wings noticed.

8.46.—One cheel up near Agra Club. Eighteen circling in city.

A year later a similar succession of phenomena was observed. For instance :

April 11th, 1911. At 7.50.—Wind occasionally perceptible from west, but leaves generally still. Smoke rising and spreading out in layers. Dust haze. Eddies on shed and cemetery.

7.55.—Heat eddies slight on barrack.

8.0.—Eddies more on barrack.

8.15.—Wind coming from south-west, as shown by smoke.

8.19.—Slight eddies on bastion.

8.20.—One cheel circled and glided down up-wind.

8.21.—Slight eddies on bastion.

8.22.—Four cheels circling at low level in city, and two over Fort.

8.24.—Nine cheels circling at low level in city, and two at high level over Fort. Eddies stronger on bastion.

8.26.—Seven cheels circling at low level, and three at high level over city.

The table on the following page shows the times of commencement of heat eddies and soarability together with certain meteorological data in different months of the year.

Date.	Pres- sure.	Wind.	Temp. at 8 a.m.	Hu- midity at 8 a.m.	EDDIES.			Soar- ability.
					Shed.	Ceme- tery.	Bastion.	
1910.								
Mar. 22	29.867	Calm	69.2	34	—	8.5	8.28	8.28
„ 24	29.797	„	74.2	32	8.17	8.24	8.41	8.44
April 10	29.712	W.N.W.	80.7	15	—	8.7	8.10	8.14
„ 18	29.604	S.	87.7	23	7.47	8.0	8.9	8.14
May 27	29.566	E.S.E.	92.2	45	7.4	7.7	7.9 & 7.13	7.9 & 7.14
June 1	29.551	W.	89.2	58	7.23	7.25	7.28	7.29
Aug. 7	29.419	E.S.E.	85.2	81	7.57	7.58	7.59	8.0
„ 22	29.703	„	87.7	71	6.50	6.53	6.55	6.58
Sept. 4	29.506	W.	85.2	72	7.47	7.48	7.53	7.50
„ 26	29.738	E.	87.2	76	7.15	7.15	7.25	7.38
Oct. 11	29.856	S.E.	77.7	59	8.20	8.30	1.45	8.46
„ 27	30.001	W.	71.7	56	8.37	8.42	9.18	9.20
Nov. 13	29.976	W.N.W.	66.2	57	—	—	9.34	8.37
„ 25	30.018	W.	58.2	45	at 8.50	—	9.3 & 9.7	9.5 & 9.11
Dec. 10	29.986	„	56.7	72	8.57	9.10	9.45	9.43
„ 30	30.109	E.S.E.	52.7	70	9.17	9.29	9.44	9.35
1911.								
Jan. 11	30.037	W.N.W.	59.2	82	at 9.20	—	9.23	9.24
„ 24	29.870	E.	59.2	85	at 8.55	—	9.0	9.1
Feb. 8	30.026	S.E.	53.2	58	at 8.45	—	8.56	8.56
„ 10	30.103	„	50.2	49	8.37	8.40	8.56	8.56
April 7	29.773	E.S.E.	78.7	28	at 8.40	—	8.10	8.7
„ 11	29.691	S.S.E.	82.2	31	at 7.50	—	8.19	8.22

The foregoing table contains a selection taken at random from a large number of observations. It serves to show that various meteorological factors, such as pressure, temperature, etc., have no influence on soarability, while the development of soarability is closely connected with the development of heat eddies. In two cases in the above table (May 27th, 1910, and November 25th, 1910) two figures are given for commencement of bastion eddies and soarability. In each of these cases eddies commenced on the bastion and cheels began soaring at the earlier of the two times. Then, in each case, the cheels began flap-circling or settled and the bastion eddies ceased. After an interval eddies and soarability recommenced as indicated by the second entry. In the case of December 10th and 30th

1910, no true eddies but only an appearance of distortion could be seen on the bastion at the times stated.

The facts above described amount to a strong proof that on the dates mentioned there was some connection between the development of heat eddies and the development of soarability. It remains to be discussed whether this connection is causal or merely incidental.

Before entering on this discussion it will be advisable to look back at the facts already established relating to the nature of soarability. Even the earliest observations described prove definitely that soarability is not due to the bird taking advantage of irregular and chance currents of ascending air. The existence of different modes of soaring flight, the proofs that these different modes of flight require different amounts of air energy, the regularity of circling, and other facts, prove that if soarability is due to ascending currents these currents must be of small size and must be uniformly distributed in soarable air.

Existing evidence appears to show that heat eddies are of small size and that they are uniformly distributed. Consequently, from this point of view, it is *a priori* possible that they are the cause of soarability.

The chief objection to the idea that the cause of soarability has been discovered in heat eddies is the fact that their apparent velocity is insufficient. It is a fact that the morning dust haze usually present decreases as heat eddies develop. It is probable that the dust particles that cause this haze are lifted and dispersed by the action of heat eddies. But a light downy feather will drop through air that is full of these upward currents. In a light wind a feather at some height above the earth may be seen floating along apparently

in an almost straight line. That is to say the movement of the heat eddies is so gentle that they have no observable effect on the course of a feather. According to Lanchester (*Aerodnetics*, page 263), an upward current of a velocity of 7ft. to 8ft. a second will be usually necessary to make soaring flight possible. The observations brought forward in a previous chapter on the position of the digital quill feathers of the black vulture in fast flex-gliding suggest that an even greater force than that represented by such an upward current is involved.

But it is preferable that the question as to whether heat eddies are or are not the cause of soarability should be settled not by discussion but by the actual facts of observation. The following observations show firstly, that heat eddies may exist in the absence of soarability, and secondly, that soarability may exist in the absence of heat eddies.

It is safe to assume that the heat eddies described in preceding paragraphs are caused by the heat of the sun. They may therefore be more particularly described as "sun eddies." Two other kinds of heat eddies are known to me which are not directly caused by the heat of the sun, and which have no relation to soarability. These I now propose to describe.

I have often noticed that during the daytime buildings that in the early morning had shown strong heat eddies now no longer do so. It is probable that during the day the air and the buildings have reached the same temperature, or nearly so, and that in this equilibrium no rising masses of air are formed. A reason for believing that this is the case is given by the following facts: Towards sunset there is a fall

in the temperature of the air. It therefore becomes cold relatively to the earth. Hence (in hot weather) buildings which have accumulated sun heat during the day begin at this time to warm the air in contact with them. Heat eddies are therefore produced. These heat eddies may be called "earth eddies." They usually are stronger than the heat eddies observed at the commencement of soarability. They develop and acquire intensity at a time when soarability near the earth is decreasing. For instance:

23rd March, 1910. At 4.45.—Air at low levels still soarable.

5.0.—Eddies slight on cemetery and bastion. None on Taj. Slight on Taj Mosque and Taj garden kiosk.

5.9.—Air at low levels unsoarable. No heat eddies on bastion, shed, or cemetery.

5.50.—Strong eddies on Taj Mosque, Taj, Taj garden kiosk, and on Jawab—a building which was then in the shadow of the Taj dome. Therefore, eddies are visible in shade.

In some cases these eddies appear to persist all night since in the early morning they may be seen all over the larger buildings as soon as there is light enough for them to be visible. As the sun gathers strength they die away. Observations were carried out nearly daily in April and May 1912. On seven occasions strong eddies of this nature were visible. On sixteen occasions slight earth eddies were seen. In my experience if the air in the early morning feels cold out of doors compared to the temperature indoors then these earth eddies will be observed. If there has been a hot night, owing either to cloud, or owing to the presence of dust floating in the air at high levels, then no earth eddies will be found. Some time after the earth eddies have died away, or sometimes while traces of them are still present on the higher buildings, sun eddies commence to develop on the buildings situated at a lower

level, and these are followed, as previously described, by the appearance of soarability. These earth eddies may be visible in the early morning far more strongly than are sun eddies an hour or more after soarability commences but yet the air shows no trace of soarability.

Another kind of heat eddies may be described as "air eddies," as they are produced by a current of cold air striking the heated surface of the earth. Sometimes the air of a dust-storm feels hot. Sometimes it feels cold. The latter alternative happens especially in cases in which the dust-storm is about to be followed by a shower of rain. Dust-storms in which the air feels cold may produce air eddies. This may happen in cases in which the air is not soarable or has only a low degree of soarability.

I have seen air eddies over the Fort buildings in front of an advancing rain-storm, which continued when the buildings were under heavy rain, and were visible for three or four minutes under these conditions. On one occasion (July 29th, 1910) I noticed that these air eddies (formed near a rain shower) seemed to differ from sun eddies in that they were visible on vertical as much as on horizontal lines of buildings. They also seemed more fine-grained. The air was unsoarable.

Two causes are known to me owing to which sun soarability may develop at its normal time in the complete absence of heat eddies.

Firstly, if thin cloud covers the sun the energy that produces heat eddies appears to be held back, while the energy that causes soarability appears to be present in the sun's rays, with little or no diminution in most cases. The following table includes examples

of this occurrence, which it may be noted, have been recorded at different seasons of the year :

Date.	Pres- sure.	Wind.	Temp. at 8 a.m.	Hu- midity	Soar- ability began at	Remarks.
June 2	29.588	S.	90.2	50	7.51	Patches of cloud, slight eddies on shed
July 22	29.621	W.N.W.	91.2	56	7.40	Glare, no eddies ; soar-ability developed gradually
Aug. 9	29.457	N.E.	87.2	74	6.55	Thin cloud, no eddies
„ 12	29.411	W.S.W.	81.2	87	8.6	Glare, no eddies
„ 13	29.458	S.S.E.	81.2	81	7.55	„
„ 26	29.659	E.	81.7	89	7.20	„
„ 27	29.659	W.	81.2	91	8.20	„
Sept. 7	29.434	W.N.W.	79.2	91	8.0	„ Similar results on three following days
Nov. 9	29.944	E.S.E.	69.2	70	9.4	Glare, no eddies
Dec. 23	30.080	W.N.W.	47.7	49	10.5	Cloud, no eddies
1911.						
Jan. 8	30.157	Calm	54.7	90	9.33	Cloud, no eddies
„ 9	30.143	„	59.7	85	9.30	„

The second cause that may prevent the appearance of heat eddies is the presence of a large quantity of dust floating in the air at high levels.¹ The accompanying fig. 84 shows the observed times of commencement of sun soarability on different dates in the month of May in 1911, and in May 1912. During the first of these two months I observed no dust-storms and there is no mention of dust-storms in the official meteorological records. Almost without exception during this month on days on which sun soarability was observed heat eddies on the Fort bastion developed at about the same time as the soarability. On the other hand, in May, 1912, dust-storms frequently occurred in the evening or afternoon and during the day dusty winds were often

¹ The hot dry winds that blow over the plains of India during the hot weather have the power of lifting dust to great heights. Some years ago a heavy fall of this dust occurred in Naini Tal at a height of over 7,000 feet above sea level. Some of it was collected and sent to me with the enquiry whether it was not derived from some volcanic outburst. Analysis showed it to be of identical composition with the dust found on the roads in the plains.

blowing and raising dust to great heights. On several occasions, during the latter half of the month, much dust was visible floating in the air and no trace of heat

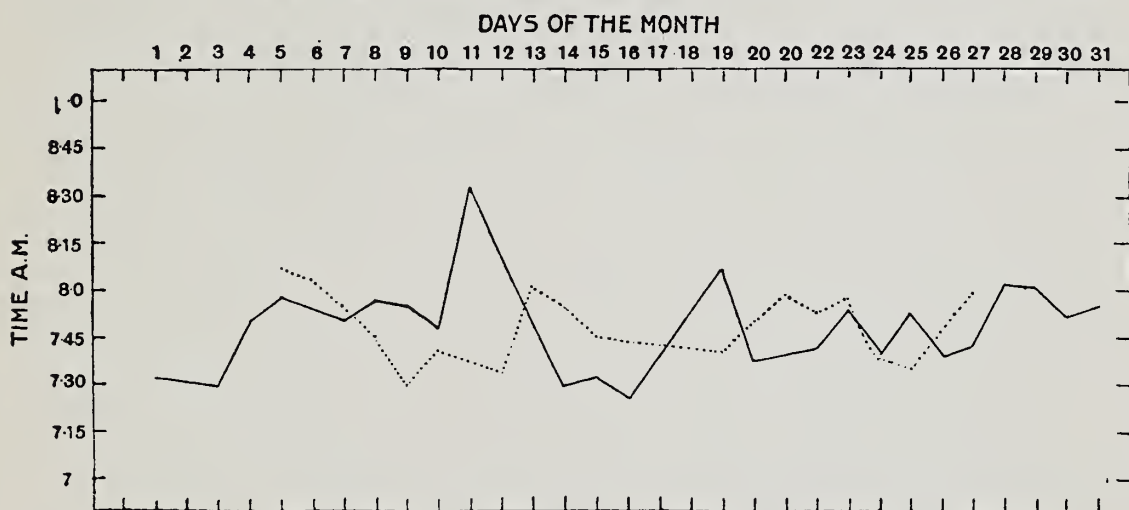


FIG. 84.

Curves showing times of commencement of sun soarability in Agra in May, 1911 (dotted lines), and in May, 1912 (continuous lines).

eddies developed. In spite of this, sun soarability developed much about its usual time. The following table shows data recorded in the second half of May, 1912:

Date.	Condition of Air.	Sun Soarability developed at	Bastion Eddies developed at	Dust Storms recorded at
May 17 ..	Dusty	7.42 a.m.	None	—
„ 19 ..	Haze	8.8 a.m.	8.5 a.m.	—
„ 24 ..	Dusty	7.38 a.m.	None	6.0 p.m.
„ 25 ..	Clear	7.53 a.m.	7.44 a.m.	7.0 p.m.
„ 26 ..	„	7.38 a.m.	7.38 a.m.	9.0 p.m.
„ 27 ..	Dusty	7.42 a.m.	None	—
„ 28 ..	„	8.2 a.m.	8.4 a.m.	6.30 p.m.
„ 29 ..	„	8.1 a.m.	8.2 a.m.	—
„ 30 ..	Clear	7.52 a.m.	7.54 a.m.	5.0 p.m.
„ 31 ..	Dusty	7.55 a.m.	None	2.30 p.m.

In the above cases the dusty appearance of the air was due to dust floating at high levels, which dust had probably been lifted by the afternoon dust-storms of the preceding days. Masses of dust,

in some cases somewhat resembling thin cirrus cloud, could be seen floating in the air and the blue of the sky was much diminished by its presence. Outlines of buildings could be clearly seen. The appearances produced by the morning haze are quite different. If haze is present the sky overhead is, or may be, of full blue colour. Clouds (if present) overhead are seen sharply defined. On the other hand objects at low levels are indistinctly seen. This haze may in some cases make heat eddies difficult to see. Besides the instances quoted in the above table high-level dust interfered with the production of heat eddies on two other occasions during this month. On one of these barrack eddies were seen. That is to say the interference with the formation of heat eddies was not complete. In another case eddies were absent but the exact time of commencement of soarability was not noted.

All available evidence goes to show that if eddies exist in the early morning they are readily visible unless the air is thick from heavy haze, or rarely if damp winds are blowing across the line of sight. It occasionally occurs that eddies are visible under cloud shadow. For instance, in the following striking case, eddies in the early morning were visible under cloud shadow without soarability. The eddies gradually diminished and vanished and after they had gone the air became soarable to a slight degree :

September 21st, 1910. At 6.45.—Cloud in two layers. The lower layer moving slowly from north. Wind cold, puffy, moving small branches. No sunshine or glare. Strong eddies on Students' Hostel, Sekundra, cemetery, shed, bastion, barracks, and city houses. No cheels up.

7.0.—Eddies as before. No glare. No cheels up, except cheels in ascending current over Delhi Gate of Fort. These were gliding at low level.

7.15.—Eddies on hostel slight. Sekundra, no eddies, but it appeared as if out of focus. Strong eddies on city houses, slight on bastion. Strong on barracks. Slight on cemetery. Shed appeared as if in bad focus.

7.20.—No sun. No glare.

7.30.—No cheels up. Slight eddies on hostel, city houses, barracks. None on Sekundra, bastion, shed, or cemetery. Glare.

7.45.—Eddies on hostel, and slight on barracks. None on city houses, Sekundra, shed, cemetery, or bastion. No cheels up.

8.5.—No eddies anywhere.

8.7.—Five cheels circling at low level in far part of the city; they appear to be in strong glare or sunshine.

8.16.—Five cheels circling and two skimming over buildings.

8.20.—No cheels up. No eddies. Glare.

8.25.—Eight cheels flap-circling.

9.30.—Cheels lee-looping.

10.0.—Thin cirrus over sun. No eddies, except on hostel. Cheels and scavengers circling both at low and high levels. No flex-gliding. Cheels flapping for going up-wind.

10.3.—Two cheels seen flex-gliding, and one scavenger flex-gliding with loss of height and then flap-gliding.

Thus we have seen that soarability can exist under a variety of atmospheric conditions in the absence of heat eddies. Conversely heat eddies can exist in air that is completely unsoarable. No stronger proof can be required that one phenomenon is not the cause of the other.

Thus the rising masses of heated air caused by the sun's rays, whose presence is revealed by the shimmering tremulous appearance that they give to solid objects, cannot be invoked as an explanation of soarability. If soarability is due to ascending currents caused by the sun's rays, the ascending currents must resemble heat eddies in being widely and apparently uniformly distributed. They must differ from heat eddies in containing a great deal more energy and in being as yet undiscovered.

On a hot calm day large whirlwinds or dust-devils are often observed. These raise dust, pieces of paper, leaves, etc., to a height of several hundred metres. It might be suggested that a layer of highly heated air has formed over the surface of the earth, that this at last

breaks through the superincumbent colder layer of air at one place. The hot air rushing upwards at this place may be supposed to acquire a rotary motion for the same reason that a similar motion is acquired by water running out of a bath when the plug is taken out of the escape pipe. But if this explanation is correct one would expect some evidence to exist of horizontal currents rushing centripetally towards the whirlwind. Further, such an explanation does not explain why these whirlwinds should be rare in Agra and common in Rajputana, as elsewhere stated. Neither does such an explanation harmonise with the observations of Mr. V. Bayley of whirlwinds forming at a height and descending to earth.

Whether or not the above-suggested explanation is correct for large whirlwinds that raise dust up to a height of several hundred metres it may be doubted whether it is correct for smaller dust-devils which may occur in a fairly strong wind, in view of the following observations :

20th October, 1911. At 1.45.—A small dust-devil, about 2 metres in diameter and 3 metres high, seen travelling along the road. It had an inner central core of denser dust, about $\frac{1}{4}$ metre in diameter. This was sharply marked off from the thinner outer layers. The central core appeared to be descending and to be rotating in a direction opposite to that of the outer layers. (Possibly this appearance was due to its speed of rotation being much less than that of the outer part of the dust-devil.)

25th May, 1912. At 7.0 p.m.—A grey dust-storm. Cheels rose, and soon settled. No tail-jolting. Slight lateral instability shown.

7.15.—A wide open road near house. I noticed a small mass of dust blown up by the wind. It was perhaps 2 metres across and of an equal height. It was travelling rapidly to leeward. Suddenly the greater part of the mass of dust acquired a cylindrical shape and rapid rotation round its axis, which was nearly vertical. After rotating for a second or two it dispersed with explosive suddenness, losing instantly all trace of rotary motion. The dust composing it spread out to leeward like a fan. With a rapidity almost too quick for the eye to follow, the dust-devil changed into a thin diffuse irregular wall of dust situated some 20 or 30 metres to leeward.

In the second of these instances there was so much dust irregularly dispersed in the air that had there been any inrushing current towards the dust-devil it would almost certainly have been visible. There was an appearance of a loss of speed to leeward as the dust-devil developed. That is to say, had an anemometer been situated just to leeward of this dust-devil, it is likely that it would have registered a sudden fall of wind velocity while the whirlwind was forming, and a sudden increase of velocity as it exploded.

2nd December, 1912.—Fine. Wind west moving small branches. much dust rising. A dust-devil seen at 12.0. It was about 3 metres high and rotating very rapidly. It had a transparent central core sharply marked off from the rest.

3.30. By Railway Bridge.—A mass of dust rising. It was about 3 metres in diameter. Suddenly three small dust-devils formed on its periphery. Then these ceased and the whole mass turned into one large dust-devil, which in a moment dissipated.

Small dust-devils more usually dissipate suddenly on contact with some solid object, such as a tree. The suddenness of their dissipation and their high speeds of rotation are facts not easily harmonising with the idea that they are caused by inrushing currents of air.

It is obvious that the larger dust-devils occur so infrequently, and are so local in their effects, that it is impossible to invoke them as an explanation of soarability.

CHAPTER XVI.

WIND SOARABILITY.

In the preceding chapter I have shown that, as a rule, the kind of soarability that I have described as “sun soarability” develops at a definite time of the day, and that this time coincides with the appearance of heat eddies on a particular bastion in the Agra Fort. The exceptions to this rule hitherto mentioned have been cases in which bastion heat eddies do not develop

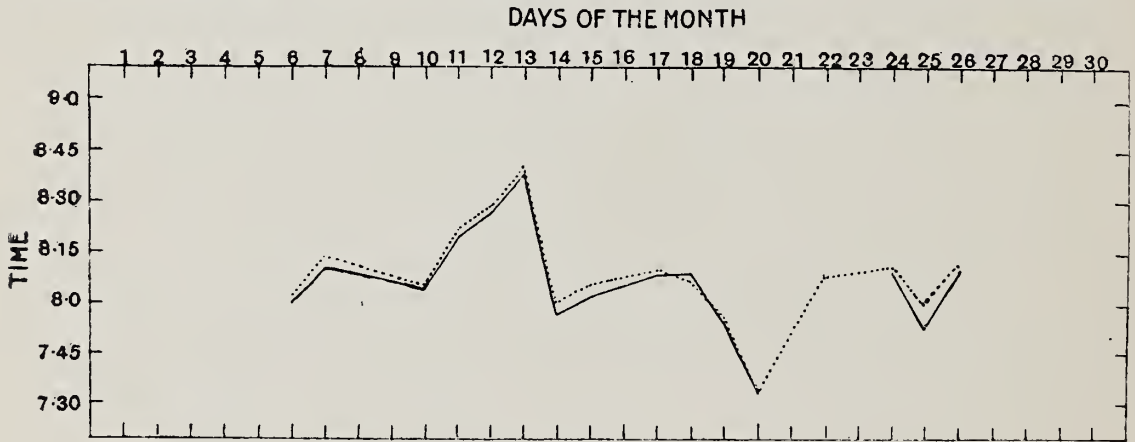


FIG. 85.

Curves showing daily times of appearance of heat eddies on the Bastion by Umar Singh Gate of Agra Fort (continuous line) and times of development of sun soarability in Agra city (dotted lines).

Both curves refer to the month of April, 1910.

owing to part of the energy of the sun's rays being cut off either by the presence of thin cloud or owing to the presence of masses of dust floating in the air at high levels. I have now to describe other exceptions which will be found to be of an entirely different nature.

In fig. 85 the results of certain observations made during April, 1911, are shown in the form of curves. The continuous line represents the times of appearance of sun soarability, and the dotted line shows the times of appearance of bastion eddies on the different

dates indicated. As shown by the closely superposed curves there was a connection between development of bastion eddies and soarability on each of the twelve observations made up to the 20th April. The wind strength on these twelve days was as follows :

Once, wind moving small branches.

Twice, wind moving leaves.

Three times, wind perceptible to touch only.

Three times, wind direction indicated by movement of smoke.

Three times, no wind direction discoverable by movement of smoke or otherwise—that is to say, air apparently calm.

The above were all cases of “sun soarability.” This form of soarability also occurred on the 22nd April but in the absence of bastion eddies presumably because, as stated in my notes, the sun was obscured by cirrus cloud. On the 24th, 25th, and 26th, sun soarability was also observed. But on the following two days, in each case in the presence of strong wind, soarability developed long before the appearance of bastion eddies. Further observations made during the following months gave a clue to the nature of the phenomenon.

On the 27th May 1911, sun soarability commenced at 7.58, and bastion eddies two minutes later. But previously, at 7.50, during a puff of wind a cheel near me commenced circling and settled as the wind died away. That is to say temporary and local soarability coincided with a gust of wind.

On the 30th May, temporary local soarability was observed both at 7.23 and 7.27, in each case during gusts of wind.

On the 1st June, sun soarability and bastion eddies developed at 7.25. But at 7.0, during a gust of wind, a cheel was seen lee-looping for a short time.

On the 6th June, at 6.54, soarability had already developed, in the absence of heat eddies from bastion and other buildings, at the time of commencement of my observations. A strong south-west wind was blowing.

On the 8th June I made the following observations :

6.35.—Observations commenced at this time. Cheels circling. No eddies. Wind east, moving branches. Thin cirrus cloud moving from south-east. Sunshine at intervals. Cheels gliding up-wind showed loss of height.

7.15.—Cheels gliding up-wind showed much instability, often loss of height, and no flex-gliding.

7.30.—Slight sunshine. Cheels slow speed flex-gliding up-wind.

On the 9th June, soarability also developed long before the normal time for development of sun soarability :

6.0.—Wind east, moving smaller branches.

6.5.—Cheels seen skimming over buildings in city, and settled at 6.7.

6.12.—Eight cheels circling.

6.35.—Twelve cheels circling mostly at low level. They were unstable when gliding up-wind.

6.58.—Wind increasing. No eddies on Fort or city. Cheels gliding up-wind showed scarcely any instability.

Again, on the 10th June, soarability was seen in the presence of wind and in absence of eddies :

6.0.—Wind east, moving small branches. No eddies.

6.10.—Eleven cheels and one scavenger circling.

6.15.—Six cheels circling on north side of town, where there appeared to be wind, as indicated by smoke of factory chimneys. No cheels up in the south part of the town, where it appeared to be calm.

6.27.—Five cheels up either skimming over buildings or flapping. Wind less, moving leaves only.

6.35.—Nine circling in north part of city. Some of these were at high levels. This was in presence of wind, as shown by fast moving smoke. Two cheels near gliding down. Wind here moving leaves only.

6.40.—Cheel lee-looping in gust of wind in Taj direction.

6.45.—Cheels circling near. Wind very light.

6.56.—Twenty-four cheels up over city.

6.57.—Eddies on shed, cemetery at 6.59, and barrack at 7.0.

7.3.—Eddies on bastion. Twenty-eight cheels up in city.

Similar phenomena were seen a year later :

1st April, 1912. At 7.30.—Wind east, moving small branches in puffs. Air clear. Sekundra visible. Sky half clouded. Sunshine. No eddies on bastion. Slight eddies on cemetery. Cheels up in city and near.

7.45.—Shade all over city. Cheels there circling as before.

8.0.—Shade in city, and also a lull in the wind, as shown by smoke from a train. Cheels in city often flapping. Calm also here, and cheels near flapping or settled.

8.2.—A cheel gliding down showed digital quill gap of inside wing for steering.

8.5.—Wind here. Three cheels near circling.

8.14.—Wind in city, as shown by flag on fort. Cheel there circling without flapping.

8.16.—Lull in city, as shown by Fort flag. Some cheels flapping.

It is needless to multiply examples. We are dealing with a form of soarability which differs from sun soarability in the following particulars :

(1.) It only occurs in the presence of wind. As elsewhere shown sun soarability exists independently of wind and is shown in its highest form in the apparent absence of wind.

(2.) Sun soarability only exists in the presence of a sufficient degree of direct sun energy, as shown by its usual connection with bastion heat eddies in Agra, and by cases of cheels soaring when enveloped in thin cloud in Naini Tal, which soaring it will be recollected came to a stop when thicker cloud rolled up overhead so as to diminish the intensity of the glare. The form of soarability we are now dealing with may occur both in the morning twilight and long after sunset. It occurs in its highest form in stormy winds under heavy cloud.

I propose the term “wind soarability” for the phenomenon in question.

Besides in the above-mentioned characters, wind soarability differs from sun soarability in that the latter usually commences first over the city, and only after an interval of several minutes do cheels begin circling over the cantonment. Wind soarability begins wherever there is wind, and in many cases this happens locally over parts of the cantonment before its appearance over

the city. Sun soarability begins at a definite time in the morning, varying with the time of year. Wind soarability may commence an hour or more earlier. Sun soarability commences with circling, and generally within a few minutes the air becomes suitable for flex-gliding. In wind soarability, in certain cases, only sufficient energy is present for circling. In other cases, as in dust-storms, slow flex-gliding appears from the commencement. Hence it is usually possible to determine whether the soarability that develops in the morning is due to sun or wind. In some cases local and temporary wind soarability precedes the appearance of widespread sun soarability. The following table gives the numbers of days on which different kinds of soarability were observed in the early morning in the years 1910, 1911, and part of 1912 :

	Sun	Wind followed		Wind
	Soarability.	by Sun	Soarability.	Soarability.
January ..	35	..	0	1
February .	25	..	2	0
March ..	36	..	2	2
April ..	49	..	4	8
May ..	54	..	11	17
June ..	20	..	3	7
July ..	5	..	6	21
August ..	24	..	11	15
September .	34	..	9	6
October ..	43	..	0	2
November ..	30	..	1	2
December .	24	..	1	0

From these data it may be calculated that wind soarability may be expected to occur on—

1 day in January	25 days in July
0 „ February	12 „ August
1½ days in March	4½ „ September
4 „ April	½ day in October
7½ „ May	2 days in November
7 „ June	0 „ December

It may be noted that in April, May, and June, the weather is intensely hot, and is apt to be disturbed by dust-storms. The damp monsoon winds usually, in my experience, reach Agra at the beginning of July, and continue with less intensity during August and September.

The first question that arises in connection with wind soarability is whether it is due to birds taking advantage of air currents reflected up from trees or buildings, which currents must exist in the presence of wind.

In the first place it must be premised that it is easy to recognise the use of such ascending currents by birds, and that, in sun soarability and in wind soarability of high degree, they take some pains to avoid such currents. For instance :

1st June, 1910. At 1.10.—Calm after heavy shower of rain. No heat eddies visible. Cloud. No birds up except one cheel flapping.

3.0.—Glare and slight sunshine. Heat eddies on cemetery. Cheels and scavengers circling.

4.45.—Shade. Strong puffy east wind, sometimes moving branches. Vultures at a height flex-gliding and lee-looping. Cheels at low levels taking advantage of ascending currents. Five were to windward of house, many to windward of Jawab (a high building), and others to windward of Fort. Six were up in the city circling at low level, with occasional flapping.

5.8.—Glare. Sun coming out. Cheels at once left house, Fort, and Jawab. They were seen circling high over the city as the sun got stronger at 5.12.

That is to say, in the absence of sun energy, and in an unsoarable wind, birds took advantage of ascending currents. In true wind soarability such ascending currents are as a rule avoided, and birds are seen flex-gliding for long distances up-wind or lee-looping far to leeward. Thus in their flight they do not remain exposed to the influence of any one ascending current.

In wind soarability the amount of soarability frequently appears to be more at a height than at low

levels. Ascending currents reflected up from buildings must be stronger, if not so extended, at low levels. In the following case wind soarability existed at a height only :

22nd July, 1912. At 8.0.—Heavy low level clouds moving fast from east. Wind east, beginning to move small branches. Cheels at low level flap-gliding. Twelve cheels in ascending current to windward of house. Air soarable at from 100 to 200 metres height.

8.5.—A cheel slow flex-gliding at 200 metres. Swifts at about 100 metres height showed much less flapping than usual.

8.6.—Two cheels at 100 metres lee-looping, and showing slow drift to leeward, proving that wind was not much stronger at that height than below.

8.8.—Several cheels slow flex-gliding at 150 metres from the east with occasional flapping. A cheel did not start flapping when it arrived at a place where another cheel had flapped, that is to say, there was no reason for believing that flapping was due to lack of uniformity in the soarability of the air. It is more probable that the air energy was only sufficient for slow flex-gliding ; and the cheels, being in a hurry to get away from approaching rain, occasionally flapped to increase speed.

8.9.—Five cheels, at about 300 metres, circling in and out of under-side of a cloud.

8.10.—Shower of rain.

In an unsoarable wind there is some relation between its strength and the height to which birds are carried in upwardly reflected currents. In wind soarability, not only are birds, occasionally at least, seen soaring at much greater heights than are attained by the help of known ascending currents, but the degree of wind soarability sometimes is and sometimes is not proportional to the strength of the wind.

As an example of the second alternative the following may be quoted. In this instance wind soarability occurred in the presence of an extremely light wind :

25th April, 1912. At 5.55 a.m.—Wind east, moving leaves. Smoke in discrete masses. Air clear. Sky one-third clouded. Shade here. Scavengers near, flap-circling and then flap-gliding, showed lateral instability. No eddies.

6.3.—Cheels circling in city, and gliding up-wind with loss of height.

6.7.—Six cheels circling or flap-circling in city. Fort flag moving.

6.14.—Fort flag still. In city two cheels up in flapping flight near Fort.

6.20.—Smoke in city rising vertically. No cheels up there.

6.29.—Two cheels circled in Taj Gunj, and settled.

6.30.—An eagle near gliding up-wind with loss of height showed lateral instability. Wind near it moving leaves.

6.34.—Cheel circling in Taj Gunj. Judging from its drift it was in wind.

7.0.—Smoke nearly vertical in city, and no cheels up.

7.11.—Wind here moving small branches in a puff. Cheel overhead showed slight dorso-ventral axis instability.

7.14.—One cheel gliding down, and one circling in city.

7.22.—Six circling in city. Eddies strong on bastion.

The above is a case of wind soarability in a very light wind, followed by sun soarability after the wind had dropped. Examples of the contrary alternative, namely, some signs of a relation between the soarability and the wind strength, are commonly seen as the wind falls after a dust-storm. During the storm cheels are mostly to be seen wind-facing or gliding up-wind horizontally with wings slightly flexed. As the storm dies away this power of travelling up-wind decreases, in that the cheels no longer go up-wind horizontally with wings flexed. In some cases they are seen to use lift-gliding with gain of height. This is soon replaced by lift-gliding with loss of height or the cheels employ flapping flight. While this change is occurring cheels no longer are seen wind-facing. When not travelling up-wind they are circling or lee-looping.

Further proof that wind soarability is not due to the birds taking advantage of upwardly reflected currents is to be found in the frequent existence of unsoarable winds. It is the rule that on any day on which sun soarability develops, if wind is previously present, cheels when up are always in flap-gliding flight. Further, the wing adjustments used in wind soarability are identical with those used in sun soarability and are to an equal degree different from those employed for gliding in an ascending current.

Therefore if wind soarability is due to ascending currents, these must be of a different nature from the upwardly reflected currents known to exist.

It is safe to assume that all manifestations of energy in the atmosphere are ultimately derived from sun energy. Therefore if wind soarability is due to ascending currents, these currents must be derived from sun energy. Since wind soarability may be manifested at sunrise, when direct sun energy cannot be invoked as the source of energy, it may be argued, that the ascending currents that cause wind soarability must have the property of being able to persist all night.

But there is reason for believing that in the early morning a wind-gust develops locally. An alternative view would be that wind exists at a height and that occasionally an isolated current from this wind descends to lower levels, appearing as a gust. Whether or not this is the case with early morning gusts in Agra might be tested by sending up small balloons in order to see whether at this time there is wind overhead. In the absence of such direct evidence it may be pointed out that in a type of weather not infrequent in Agra a few cumulus clouds are seen travelling across the sky during the day. At evening they change to stratus clouds and lose their speed ahead. If, as is a frequent custom during the hot weather, one sleeps out of doors, a cloud of this nature seen in the evening may be again seen during the night in the same position and be again recognised on the following morning. That is to say the calm that persists all night at ground level corresponds to a similar calm at high levels. In the morning soarability develops for cheels. More often than not gusts of wind develop after this has happened. These

gusts may change to a comparatively lasting wind by about the time that the air is soarable for vultures. It is only after these phenomena have occurred that the clouds gradually change from stratus to cumulus and begin to move ahead. That is to say existing evidence tends to show that both wind and soarability begin at low levels and later in the day extend to high levels. A gust is mentioned in a later paragraph that affected strongly the lower branches of a tree while having very little effect on the higher branches. Within a small area these early morning gusts may be blowing in widely different directions. In such weather neither dust, haze, nor smoke gives evidence of the existence of wind at a height in the early morning of sufficient strength to account for the appearance of gusts. On the other hand, during the day, after the wind has become established, evidence is readily obtainable, in many cases, that the air moves at a greater velocity at a height than at ground level, and it would then be less easy to exclude the possibility of a gust being caused by high-level wind momentarily descending towards the earth. I have consulted several books on meteorology and to my surprise found that they contained no explanation either of gusts, whirlwinds, dust-storms, or tornadoes. Of the various local manifestations of energy that take place in the air, soaring flight appears to be the only one about which theories unsupported by facts have been brought forward as explanations.

Thus there are grounds for believing that in the formation of a gust, air apparently at rest and incapable of supporting soaring flight changes into air in motion and capable of supporting soaring flight. Hence, if such soaring flight is due to movements of parts of

the air, these movements must be arranged in one way while the air is at rest, and in another way (in which their energy is available for soaring) when the apparent calm is replaced by wind. On this supposition, the currents that cause soaring flight must be able to persist all night, or perhaps for longer periods, in a form in which their energy is not available.

It has been surmised that the cause of a wind gust is a difference of pressure between the air in one place and the air in another place, and that the air flows from the area of high pressure to the area of low pressure. The facts now brought forward amply prove that this simple conception of the origin of a gust of wind is insufficient. Some gusts of wind are incapable of supporting soaring flight. Other gusts of wind have the power of supplying energy for soaring flight. The facts brought forward fully prove that the difference is not connected with a difference in intensity. A strong wind or wind gust may be unsoarable, and a light wind or wind gust may be soarable.

Similarly it is a known fact that in the plains of India some winds have the power of raising dust. Other winds, which may be more powerful, have little or no such power. No speculation about difference in pressure in two different areas will explain the difference. As with wind soarability, so with dust raising, we are dealing with a power of manifesting energy which may or may not be present in a wind gust. The following facts show that, in some cases, there is a connection between the two phenomena :

12th May, 1912. At 5.15.—Daybreak. Wind just beginning, from north-east, occasionally moving small branches. Cheels showing lateral instability.

5.45.—Cheel circling. A scavenger showing lateral instability.

5.51.—A cheel showing dorso-ventral axis instability.

6.0.—A cheel showing strong dorso-ventral axis instability.

6.13.—Cheels showing slight dorso-ventral axis instability.

6.29.—Ditto.

6.40.—Cheel in a puff showing strong dorso-ventral axis instability.

7.0.—Dorso-ventral axis instability noticed.

7.17.—Cheel showing slight transverse axis instability.

7.18.—Wind increasing.

7.20.—No dorso-ventral axis instability.

7.21.—Air now getting dusty.

7.27.—Air getting more dusty. Clouds of dust blowing off roads, but no increase in strength of wind observable. Cheels showing transverse axis instability and no dorso-ventral axis instability.

7.55.—Strongly marked transverse axis instability seen.

15th May, 1912. At 7.27.—Puff of wind here raising dust. Cheel gliding up-wind showed tail jolting, *i.e.*, transverse axis instability. None had been observed previously, and none was seen afterwards, neither did dust-raising puffs occur.

In each of the above cases, which are of wind soarability, and which have been much abbreviated from my notes, the appearance of transverse axis instability more or less closely coincided with a development of the dust-raising properties of the wind. In the next chapter I shall show that in dust-storms a high degree of transverse axis instability is generally, but not always, observed. Conversely, transverse axis instability may be seen in winds that have no appreciable power of raising dust. That is to say, the two phenomena are sometimes, but not always, connected.

Further facts relating to wind soarability will be found in the following chapter, in which I shall describe the phenomena of soaring flight as witnessed in stormy winds.

I have now to describe a very important subject, namely, the phenomena of instability shown in soaring flight. These phenomena appear to be of the nature of exceptions. The rule is that in fine and undisturbed weather the soaring bird flies steadily. The exception (though a frequent exception) is for it to be unstable. It

is always of importance to study exceptions. If soaring flight is due to ascending currents and if these currents usually lift the bird steadily, then we may hope to get some clue to their nature by studying the exceptional cases in which they lift the bird unsteadily.

Thus the first question we have to settle about instability is whether it is due to chance wind irregularities, or on the other hand, whether it is due to some irregularity in the particular condition or quality of the air that is the cause of soarability.

It is generally the rule that in completely unsoarable air birds are steady in their flight. Cheels flap-gliding at sunrise and cheels returning to roost after sunset in Agra, when gliding, usually travel with singularly regular and even motion.

Signs of instability consist of rotations round either the dorso-ventral, the transverse, or the longitudinal axes.

To and fro rotations round the dorso-ventral axis, I propose to describe as "dorso-ventral axis instability." A small to and fro rotation round this axis does not appreciably produce a change of course. The bird combats such a rotation by rotating one wing. This is usually seen as a depression of the wing rotated. Rarely in stormy winds rotations of one wing may occur which are so rapid and transitory that no appearance of depression is produced. Cheels, at all events, never attempt to combat dorso-ventral axis instability by wing-tip depressions. Occasionally rotation round the dorso-ventral axis is observed. More commonly this form of instability is only recognised by the single wing depression by which it is combated.

A tendency to rotate upwards round the transverse axis I shall refer to as "transverse axis instability." This

is usually combated by the adjustment I have elsewhere described as tail-jolting. In extreme cases besides an upward jolting of the tail there is an increase in the flexing of the wings, the secondaries are relaxed, and there is a small double-dip movement. That is to say, efforts are made to bring backwards the centre of effort of the wings. Thus there is evidence of a tendency of the bird to tip upwards round its transverse axis. This form of instability is usually revealed by the tail-jolting movement. In certain cases, which will be described below, an actual tipping-up round the transverse axis is observed.

Rotations round the longitudinal axis I propose to describe as "lateral instability." These rotations are seen and recognised as such. There is no evidence of any attempt on the part of the bird to check such rotations. If such attempts are made they would consist of advancing or retiring of one wing to an extent too small to be observed.

Supposing that soaring flight is due to ascending currents and that these currents may in some cases produce instability, then, in the absence of evidence, we may imagine that the different kinds of instability are produced as follows: Firstly, if an ascending current strikes one wing without affecting the other wing, then we may expect to see an appearance of lateral instability. Secondly, since ascending currents not only lift but also propel, one may anticipate that especially in the case of lighter birds if an ascending current strikes one wing and not the other the wing affected would be driven ahead. That is to say, an appearance of dorso-ventral axis instability would be produced. Thirdly, if the bird glided into an ascending current, and met it

in such a way that both wings were equally affected, then one might expect a tipping upwards round the transverse axis ; *i.e.* signs of transverse axis instability.

If this conception represented the truth then one would expect to meet these different kinds of instability in the same wind. But as a matter of fact it is exceptional to see transverse axis instability in a wind that produces dorso-ventral or lateral instability. It is obviously inconceivable that in one wind birds should often show lifting or driving ahead of one wing, while that in another wind the supposititious ascending currents should often lift both wings equally, and never happen to strike one wing alone. In short this fact of different kinds of instability being met with as a rule in different winds or at least at different times, is a definite proof that the phenomena in question are not due to ascending currents and nothing else. In the absence of evidence to the contrary, it may be admitted that dorso-ventral axis instability and lateral instability might be due to the local or one-sided action of ascending currents, and possibly transverse axis instability may have some cause of a different nature. But evidence bearing on the point is not entirely absent. In the first place it may be noted that there can be no reason for expecting any kind of instability to be produced by an ascending current in which the bird is completely immersed. Instability would only be produced while the bird is passing from air at rest into air in motion, or *vice versa*. One would for instance expect instability to be produced when the bird glides from leeward into the ascending current reflected up from the walls of a high building. But as described in Chapter VIII. page 146, cheels in an unsoarable wind, when gliding

from leeward over the battlements of the Agra Fort, show extremely slight signs of instability when passing from comparatively still air into the ascending current. Thus an ascending current amply sufficient to support cheels in gliding flight and to permit of gain of height, is incapable under the best conditions of producing appearances of instability such as are seen in soarable winds. So if instability is due to ascending currents, these currents must be very much stronger than the current reflected up from the Agra Fort walls in a light wind. Supposing the bird is gliding from the leeward side directly in an up-wind direction, so that when it meets the ascending current both wings are equally affected, it is not *a priori* probable that an appreciable amount of tipping up round the transverse axis would be produced. A couple tending to produce such tipping up would only exist when the front part of the wings was in the ascending current and the hinder part of the wings was in still air. Such a condition would only exist for a very minute fraction of a second. The available force acting for so short a time is not likely to produce an appreciable transverse axis rotation, and as a matter of fact no rotation of this nature is observed at the moment of passage from still air into the ascending current. Supposing a bird is travelling up-wind, then a sudden increase in wind velocity is, in the absence of evidence, a possible cause of transverse axis instability. The bird combats such instability by movements likely to bring backwards the position of the centre of effort of the wings, suggesting that the instability is due to the centre of effort having been advanced in position as would in accordance with known principles, occur on passing into wind of greater

velocity. But, as we shall see, it is difficult to understand how pre-existing variations of wind velocity should, in "tail-jolting winds" always affect both wings to an equal degree.

After this preliminary discussion it will be well to consider in further detail the facts of the case.

Lateral instability of heavier birds, such as the black vulture, is seen best late in the afternoon when soarability near the earth is decreasing. But the black vulture may also show lateral instability at any other time of the day, usually to a lesser degree, provided it is at a sufficiently low level. Lateral instability, in all birds so far as I am aware, only occurs at low levels. Usually birds of lighter loading, such as the cheel, show dorso-ventral axis instability in air in which the heavier birds show lateral instability. At a time when birds at low levels are showing lateral instability, birds at higher levels may show transverse axis instability. Lateral instability may occur when the air is nearly calm. That this form of instability is connected with some lack of uniformity in the air is indicated by the following observations :

29th May, 1911. At 7.15.—Wind soarability. Cheels, scavengers, an eagle, and a black vulture circling. The black vulture was watched for about ten minutes. Every two or three minutes there was a period of flapping, which lasted a few seconds. A period of lateral oscillation always preceded a period of flapping.

17th May, 1912. At 7.20.—A cheel near gliding up-wind with wings even. It was in steady flight. Then suddenly it showed lateral instability. After gliding thus for about 2 metres, it flapped. Wind south, moving leaves.

7.25.—Another cheel circling near. Twice it showed slight lateral instability just before flapping.

Thus we see in these cases the birds glided from air that supported them in steady flight to air that only supported them with signs of lateral instability, and

immediately afterwards found themselves in air in which it was necessary to flap. I have elsewhere (Chapter IV., page 33) described a case in which besides lateral instability and occasional flapping there was additional evidence of lack of uniformity of the air, in that a vulture during a long glide showed several slow and large changes in the angle of incidence, although it appeared to be travelling horizontally. An apparently similar instance is included in the following extract from my diary :

22nd April, 1912. At 7.10.—Cheels circling.

7.30.—Wind east, moving small branches. Air clear. Slight thin cirrus here and there not visibly moving. Cheels flapping or losing height for going up-wind. They were usually steady. One showed two slight double dips. When at low level slight single wing depressions and also slight lateral instability observed.

7.55.—Scavenger circling and gliding with wings arched showed slight lateral instability. Colour faint greyish yellow, best seen from behind.

7.57.—A black vulture, while gliding up-wind and showing slight lateral instability, made a change in the amount of advancing of the wing-tips. (This must have produced a change in the angle of incidence.)

8.25.—A cheel showed slight tail-jolting.

The above was a case of wind soarability. The extract illustrates the fact that wind soarability in the early morning is accompanied nearly always by signs of lateral and dorso-ventral axis instability. During April and May of 1912, I observed such instability on eighteen out of nineteen days on which wind soarability occurred. Instability, usually of lesser degree, may also be observed at times when sun soarability is about to develop. During April 1912, sun soarability was thus associated with instability on eight out of twenty-one occasions. In May 1912, there were twenty-one days of sun soarability, and on only two of these days were no signs of instability observed. Sometimes in wind soarability the instability is greater at first and diminishes as the day goes on.

In the following instance changes in the angle of incidence occurred at a time when only slight signs of dorso-ventral axis instability were noticed :

29th March, 1912. At 3.27.—A strong gusty wind, moving branches, had just risen, and dust was rising here and there.

4.15.—During all this time no tail-jolting was observed. Birds showed slight irregular movements of the wings (single wing depressions or rotations), as frequently seen in a strong wind. No double dips were seen, though slow and fast flex-gliding were noticed, in birds going up-wind, as the force of the wind varied. A flock of cranes seen in the distance flap-gliding. Twice the whole flock became invisible for a few seconds, owing to a change of the angle of incidence that affected all the birds equally. This was not connected with any appreciable change of course.

Transverse axis instability is only seen in the early morning in what may be described as disturbed weather, and does not occur frequently at this time. Usually lateral instability appears first, followed by dorso-ventral axis instability, while transverse axis instability as a rule is only observed when the air has acquired a comparatively high degree of soarability. The succession of different kinds of instability is illustrated by the following extract :

7th May, 1912. At 7.0.—Wind south-west. Perceptible to touch, and not moving leaves.

7.43.—Cheels in flap-gliding flight steady.

7.48.—Cheel circling near showed slight lateral instability. Wind moving small branches.

7.52.—Calm here. Above cheels settled.

7.53.—Puff here, moving small branches. Two cheels circling near.

7.56.—A cheel ease-gliding near showed single-wing depressions and changes from even to arched disposition of wings.

7.59.—Cheel gliding, with wind abeam, had secondaries taut. It showed slight tail-jolting. Four cheels circling near.

In the following instance instability accompanied temporary wind soarability, and steady flight was observed later when sun soarability developed :

4th June, 1912. At 5.10.—Twilight. A strong gust of wind moving small branches strongly, lasting for about three minutes. First, a cheel seen gliding nearly steadily. Then three cheels seen circling and gliding up-wind with single-wing depressions. They glided without loss of height. A cheel seen at 60 metres height flex-gliding.

- 5.13.—Lull. A cheel flap-gliding showed slight single-wing depressions.
 5.14.—All cheels settled.
 6.35.—Wind west, occasionally moving small branches.
 6.38.—Eagle flap-gliding steady.
 6.46.—Scavenger flap-gliding showed slight lateral instability and slight single-wing depression apparently on meeting a puff.
 6.57.—Steady flight. Also at 7.6 and 7.7.
 7.11.—Slight lateral instability. Wind moving leaves.
 7.17.—Slight lateral instability in north-west wind, moving small branches.
 7.18.—North wind, moving leaves. No birds up.
 7.22.—Cheel showed occasional single-wing depressions when flap-gliding.
 7.30.—Wind north, moving small branches.
 7.32.—Scavenger showed slight lateral instability and occasional large single-wing depressions. Wings also showed changes from flat and even to arched disposition.
 7.47.—Cheel steady.
 7.54.—Nine cheels circling in city.
 7.56.—Eddies on bastion. Twelve circling in city. (= Sun soaring-ability.)
 8.0.—Scavenger flap-gliding steady.
 8.1.—Cheel flap-gliding to north steady, except occasionally slight lateral oscillations as if preparatory for turning.

In the following example varied forms of instability were met with in a variable irregular wind :

- 6th June, 1912. At 6.25.—Wind east, moving small branches. Dusty air, and also dust at high level. Cheels and scavengers circling high.
 6.27.—In a lull, a scavenger gliding showed slight lateral instability and single-wing depressions.
 6.33.—Cheel in a puff of wind occasionally showed tail-jolting and large double dips. Then it showed occasional single-wing depressions.
 6.35.—Cheel tail-jolting in a puff.
 6.36.—Wind south, moving small branches. No cheels up.
 6.42.—Scavenger at low level in a south wind showed occasional single-wing depressions. Scavenger at 200 metres height steady, except slight changes from flat to dihedrally-down position of wings.
 6.47.—Puffs of wind from north and east in sight in same time (as shown by movement of the tree-tops).
 6.48.—Puff from east moving strongly the lower branches and slightly the higher branches of a tree. No birds up to windward of Fort.
 6.50.—Wind less. No birds up anywhere.
 6.51.—More wind from east. A leaf seen rising in an ascending current, which from its position could not have been caused by reflection upwards from either a tree or the house.
 6.55.—Dove gliding showed single-wing depressions.
 7.3.—Wind east. Cheel gliding up-wind showed frequent small double dips. A cheel lee-looping steady.

7.6.—A cheel lee-looping at 80 metres. Then it glided off, showing double dips and tail-jolting.

7.10.—Scavenger flap-gliding up-wind showed slight lateral instability and single-wing depressions. This apparently was in a lull.

Besides the above facts the following observations show that there is some connection between lateral and dorso-ventral axis instability :

1st June, 1910. At 9.17.—A black vulture circling at low level showed lateral instability all round the circle, except that it showed instead slight dorso-ventral axis instability on the windward side of the track.

8th May, 1912. At 7.53.—A cheel flap-gliding near showed lateral instability. As it got higher it showed single-wing depressions (*i.e.*, dorso-ventral axis instability) and no lateral instability. As it got still higher its flight was steady. (Sun soarability developed at 7.55.)

It will now be of interest to consider what conclusions can be drawn from the above description of the facts relating to dorso-ventral axis and lateral instability.

In the first place, it is obvious that these two forms of instability must be due to the same cause, and that this cause is a lack of homogeneity of the air. The evidence seems to show that if a bird glides from a place where "something" is present to a place where "something" is not present or not present to the same degree, then signs of lateral or dorso-ventral axis instability are produced. Whether this "something" has any connection with the cause of transverse axis instability is as yet undetermined. But the fact that the forms of instability we have discussed occur chiefly either at a time when soarability is increasing, or at a time when soarability is decreasing, indicates the probability that the unknown "something" has to do with the unknown cause of soarability. The study of soaring flight in stormy winds, to be described in the next chapter, will be found to lead to more definite conclusions.

CHAPTER XVII.

SOARING FLIGHT IN STORMY WINDS.

Supposing a cheel in a stormy wind is gliding to windward at such a speed that it remains fixed in position relatively to the earth, then it is obvious that its speed through the air must be equal to the speed of the air over the earth, or in other words to the wind velocity. Supposing the cheel is travelling up-wind at, say, ten miles an hour, and supposing the wind has a velocity of, say, forty miles an hour, then the speed of the cheel through the air must be fifty miles an hour. I am about to quote examples of such phenomena, that is to say of cases that prove that a stormy soarable wind is a form of air motion that blows a feather to leeward at one speed, and blows the complete bird to windward at another and greater speed. For instance :

23rd August, 1910. At 3.0.—A storm forming to the east. Very black clouds, and slight rain to north, east, and west.

3.30.—West wind rising. I came out of the house, and saw two cheels near gliding up-wind. Sometimes they drifted back a few feet. I went at once on to the roof. By the time I arrived, the wind had further increased, and cheels were gliding up-wind without any sign of being blown back. The rain was increasing both to the east and also, to a lesser extent, to the west. A slight amount of dust was rising. More dust was up on the farther side of the city and to the north, where it amounted to a small dust-storm. A large number of cheels were gliding up against the wind. They were flex-gliding, with secondaries relaxed, at heights of from 5 to perhaps 100 metres above the tree-tops. Their progress through the wind was continuous, though there may have been variations in their rate of travel over the ground. Among these cheels, probably between 100 and 200 in number, were two scavengers and an eagle. The wind was so strong that it was impossible for me to use a binocular. I happened to rise from my chair. The latter was instantly blown over, and slipped to leeward along the roof. Within a few yards a cheel was gliding up-wind, covering the ground at least at a walking pace. In this stormy wind,

balancing movements were made continually. They were carried out more quickly than in light winds. The cheels maintained their height apparently without effort. Dihedrally-down movements or double dips were seen more frequently than dihedrally-up movements. The birds occasionally rose or fell rapidly. If at the end of a fall, a cheel placed its wings dihedrally-up, the outer ends of the wings seemed to be bent upwards, as if from the strain. I only once observed elevation of the tail. This would have frequently occurred if ascending currents had been operative.

3.39.—Wind still very strong. A cheel rose near, and began circling. It showed scarcely any leeward drift. The circles seemed to be of rather small diameter. Movements were as ordinarily observed, except that the half-expanded tail showed some up-and-down jolting movements which are not usually seen in circling. When the cheel had gained a height of probably 20 to 30 metres above the tree-tops, it flex-glided up-wind.

The wings of cheels thus travelling up-wind were in the slow flex-gliding position. There can be no doubt that their speed through the air in this stormy wind was much greater than their speed through the air would be in fine weather with the same wing disposition.

In the study of soaring flight as seen in stormy winds we are dealing with the highest form of wind soarability. During storms we shall find rapid changes in soarability and rapid changes in the nature and degree of instability. We shall come across facts that will enable us to judge whether instability is due to wind irregularities (apart from soarability) or whether it is connected with the unknown cause of soarability. Before describing these facts it is necessary to begin with a short description of storms as commonly met with in Agra.

In the case of a small isolated dust-storm or thunder-storm, at first while it is developing, wind blows from all directions towards its centre. This wind I propose to term the "attraction wind." As the storm develops another wind commences—that I propose to term the "displacement wind." This wind appears to blow

radially outwards from the centre of the storm in all directions but most strongly in the direction in which the storm is moving. On many occasions I have seen the displacement wind blowing and forming a layer up to a height of about seventy metres above the ground, as shown by smoke of factory chimneys, while above it the attraction wind was still blowing towards the centre of the storm. As the storm advances the depth of the displacement wind rapidly increases. On the side towards which the storm is travelling, and to some extent at the sides of the storm, the displacement wind has the power of raising dust thus forming the dust-storm. At the back of the storm the displacement wind raises no dust. That is to say as a dust-storm of this character is approaching the observer from windward at first the real wind (the wind originally existing before the storm developed) dies away, and is replaced by a wind blowing towards the storm. This is the attraction wind. Then a dust-raising wind blows from the storm. This is the displacement wind. Then frequently there is a shower of rain. Afterwards as the storm is passing away to leeward the wind direction changes through 180° and blows free of dust. This again is the displacement wind.¹ Dust-storms of this type appear, in India, to be confined to the drier and hotter parts of the country. During the hot weather and monsoon seasons of 1913 I have observed numerous thunderstorms in Calcutta without once seeing any signs of an attraction wind. Mr. V. Bayley informs me that dust-storms in Rajputana present exactly the same phenomena as those I have observed in Agra.

¹ I have given a more detailed description of the development of dust-storms in Agra, in a discussion on soarability, at the Aeronautical Society, an account of which was published in the *Aeronautical Journal* for April, 1912, Vol. XVI., page 70.

In other cases, especially if the weather is more widely disturbed, there is no attraction wind. Perhaps the real wind may diminish in force as the storm approaches. There may be a period of calm, followed by a gradually rising wind which blows from the centre of the storm, or at any rate from the direction from which the storm is coming. After this wind has been blowing for from two to five minutes the wall of dust forming the dust-storm arrives generally with a great increase in the strength of the wind.

In an attraction wind a decrease of soarability, so far as I am aware, always occurs. For instance :

17th November, 1911. At 1.0 p.m.—Much cloud. Wind east, moving small branches or branches. A rain shower to the south-west—that is to say, the wind was the attraction wind to this shower. Cheels stable, except single-wing depressions.

3.18.—Wind N. to N.N.W., and occasionally moving small branches. No flex-gliding of cheels. They were gliding up-wind with no loss but occasional gain of height (= lift-gliding, which, as shown elsewhere, requires less air energy than flex-gliding).

3.33.—Cheels in city gliding up-wind with loss of height. (Proof of further decrease of soarability.)

4.0.—Rain.

27th March, 1912. At 2.0 p.m.—A heavy thunderstorm near, extending along horizon from north to south-west. Wind here east to north-east, moving leaves (*i.e.*, attraction wind). A vulture slow flex-gliding at 2,000 metres height. No sunshine or glare.

2.43.—Wind here north. Cheels circling both near and in city.

2.46.—Cheels in city flap-circling. Vultures seen overhead retreating before the storm.

2.53.—A scavenger near flap-gliding up-wind in steady flight. Cheels in city lift-gliding up-wind occasionally showed gain of height, and perhaps more often loss of height. They were in the attraction wind.

2.54.—Dust-raising wind (*i.e.*, displacement wind) had reached river near fort (to north of me). This dust was being raised locally—that is to say, it was not a dust-storm that had come from a distance.

2.57.—A black vulture in attraction wind overhead retreating. It showed lateral instability. It showed also large single-wing depressions. Once or twice a large depression of one wing was accompanied by a small depression of the other wing. This gave the impression that it was for increasing speed at moment of steering, and bore no resemblance to a double dip. Cheels and scavengers near in steady flight.

3.0.—A cheel at 600 metres height travelling towards storm showed dorso-ventral axis instability only. It was in the attraction wind. Dust-raising wind was now a few hundred yards to west of me. It was lifting dust in dense smoke-pattern masses.

3.1.—The dust now a few yards away. A cheel enveloped in the dust showed frequent tail-jolts and double dips. Two or three double dips occurred per second.

3.2.—Several cheels near in the dusty air showed extraordinarily frequent and often small double dips. Strong flexing of the wings seemed to produce only a small amount of descent.

3.5.—Hail and rain.

3.23.—Rain nearly stopped here. Storm centre now to east. Very strong earth eddies on Fort buildings and town. Wind here E.N.E., moving leaves. Only two cheels up, both in flapping flight.

3.26.—A cheel flap-gliding to leeward in steady flight. Others seen flap-gliding to west also steady.

It is interesting to notice in this last case a sudden change in the character of the instability accompanying a sudden change in the soarability of the air. In the attraction wind with diminished soarability there was lateral and dorso-ventral axis instability. In the displacement wind, as the storm advanced there was high soarability and high transverse axis instability, as shown by the frequent double-dips and tail-jolting. Lastly, after the storm had passed, in the dust-free displacement wind there was no soarability and no instability.

In the last chapter I mentioned cases in which there seemed to be a connection between dust-raising property of the air and transverse axis instability. I now propose to quote observations in which such instability was absent in the presence of dust-raising. In the following case, not only were birds in front of the dust-storm unusually stable, but also the degree of soarability was far less than usual:

23rd May, 1912. At 2.50.—Wind west, moving leaves. Heavy cloud, especially to west. Sekundra (a high building on north-west horizon) visible with wall of yellow dust beyond it. Cheels at low level either flap-circling or flap-gliding. Cheels and scavengers circling at higher levels. Cheel at a height flex-gliding in wind.

2.53.—Sekundra invisible from advance of dust.

2.54.—A puff of wind here moving small branches. Thunder.

2.55.—Cheel at 200 metres flex-gliding up-wind showed tail-jolting, generally slight, but occasionally strongly. (This was in west, *i.e.*, displacement wind.)

2.56.—Scavenger flap-gliding up-wind near and at low level showed occasional slight single-wing depressions. Occasional puffs of wind.

2.58.—Scavenger and cheels flex-gliding up-wind at low level nearly steady.

2.59.—City concealed by wall of dust. This had just reached south-west corner of the Fort. (Distance up-wind from this point to Sekundra five miles. The dust had covered this distance in between 6 and 9 mins.)

3.0.—Scavenger gliding just in front of dust in steady flight.

3.1.—Cheels 50 metres up outside dust were in steady flight. Dust arrived here. Yellowish. Cheels rapidly settling. While gliding down they were steady except very slight single-wing depressions and occasional slight tail-jolting.

3.2.—Wind moving branches.

3.5.—Dark. A window broken.

3.20.—Slight rain.

That is to say cheels in flight in an exceptionally strong wind were nearly stable. Thus, instability is not caused by wind *per se*. A similar conclusion can be drawn from the following case :

6th June, 1912. At 4.12 p.m.—Heavy cloud. Storm centre to S.S.W. Thunder continuous. Wind at factories (two miles to north of my house) was north-east, *i.e.*, attraction wind. Here wind coming in puffs from south-west = displacement wind. Cheels and scavengers retreating before the storm all in steady flight.

4.15.—Cheels flex-gliding at 500 metres. Cheels at low level ease-gliding with wings flat and even.

4.16.—Wall of dust now to south-west of me, and over parade ground. Cheels and scavengers in front of dust in steady flight. Some were leelooping in a south wind.

4.17.—Dust arrived here. Colour yellow. Three cheels seen settling one after the other at short intervals. They came down from perhaps 500 metres height by carpal descent, with wings strongly flexed, and were perfectly steady.¹ Their track in descending made an angle of about 10° with the vertical, and was inclined up-wind. When near the earth they showed one or two elevations of the tail, thus indicating the presence of ascending currents, and glided a little less steeply downwards. The wind was only moving small branches. Dust masses overhead did not show rapid movement—that is to say, the descent of the cheels was not due to the wind being too strong.

4.20.—A few drops of rain.

4.21.—Wind now strong, moving branches. Leaves occasionally being broken off.

¹ On another occasion I have seen lateral instability in carpal descent. Therefore carpal descent is not a form of flight in which instability cannot occur.

4.27.—Rain shower.

5.0.—Rain stopped. Storm centre to north-east. A strong north-east wind was blowing (= displacement wind). It was moving branches. Air clear. Cheels wind facing with single-wing depressions and occasional flapping. Slight wind canting.

5.6.—Wind less, moving small branches. Cheels settled, except one, to windward of house, and several to windward of Fort. Very strong earth eddies on Fort buildings.

In the above case, while there was no instability, there was no soarability. After the storm had passed off there was instability and soarability. The facts now brought forward indicate a connection between instability and soarability. Further light is thrown on this conclusion by the following case, in which transverse axis instability was seen to be connected with more soarability and instability round the other two axes with less soarability :

27th April, 1912. At 4.44 p.m.—A dust-storm to west at about 200 metres distance. Wind blowing from storm, slightly moving small branches. Cheels in this wind steady, except slight single-wing depressions. Glare. No sunshine.

4.45.—Dusty wind arrived. Cheels in this wind showed very strong tail-jolting. Air cool. Dust appeared rather yellow at first, and grey later on as it got thinner. The dust was in a shallow layer. Clouds and blue sky could be seen overhead.

4.47.—Some cheels near showed lateral instability and tail-jolting. This instability consisted of very sudden sharp rotations round the long axis, in which the extremities of the wings may have risen and fallen through a little more than an inch. There was no sign of dorso-ventral axis instability. Wind at the time moving small branches only.

4.48.—A cheel travelling up-wind, at speed over the earth, was showing single-wing depressions. Then in a puff it made strong double dips with tail-jolts and relaxation of secondaries. While so doing it rapidly gained height. It showed no other form of instability while tail-jolting.

4.51.—A cheel travelling up-wind with secondaries generally relaxed. On meeting a puff, as shown by movements of tree-tops below it, it made double dips and tail-jolts, and gained height.

4.47.—A cheel gliding downwards was nearly steady. Wind now often moving large branches.

5.3.—Sunshine. Wind moving branches in puffs. A cheel going up-wind occasionally flapped. It was nearly steady, but showed slight single-wing depressions, and scarcely noticeable double dips.

5.4.—A cheel showed strong double dips and tail-jolts in a puff.

5.5.—A cheel tail-jolting showed, concomitantly with jolts, double dips and relaxation of secondaries, *i.e.*, efforts to bring backwards the centre of effort of the wings.

5.13.—Two scavengers near, gliding up-wind horizontally, and showing single-wing depressions. Then meeting a puff of wind, they made very large tail-jolts and double dips. While so doing they made a rapid gain of height. They must have glided upwards to a height of 200 metres, their course making an angle of between 30° and 40° with the horizon. Previously they had been gliding at between 5 and 10 metres above the tree-tops. While gliding upwards their tail-jolts were visible for at least 200 metres with the naked eye, despite the comparatively small size of their tails as compared with those of cheels.

5.17.—A cheel seen to windward making tail-jolts and gaining height. Then it ceased to jolt tail, and showed single-wing depressions. While so doing it lost height.

5.18.—A scavenger near showed single-wing rotations accompanied by loss of height. Then it glided down and settled.

5.20.—A cheel in a puff showed tail-jolting while descending.

5.25.—Many other cheels seen showing tail-jolts in puffs and no tail-jolting, but single-wing depressions in the absence of a puff. Dust now less.

During the above storm, some thirty to fifty cheels were visible gliding in all directions within a few hundred metres distance. During the whole period of observation, not a single cheel came into the ascending current reflected upwards from the house. The dust-storm was not followed by rain, and cleared up gradually during the next half-hour.

This last-quoted case is I believe typical of what occurs during a dust-storm. At any rate it is a matter of common observation that during a dust-storm a high but varying degree of soarability is frequently met with, accompanied by high but varying amounts of transverse axis instability.

Thus we see that the turmoil of a stormy wind does not necessarily of itself produce signs of instability, or if it does the instability is too small to be observed. On the other hand a stormy wind may produce instability, and if it does, soarability is also present. Further the kind of instability varies with the kind of soarability in such a way as to leave little room for doubt that instability is produced by the cause of soarability, whatever this may be.

If it is admitted that the cause of soarability is the cause of instability, then it follows that lateral and dorso-ventral axis instability must be due to the cause of soarability not being uniformly distributed, whether this cause is ascending currents or horizontal pulsations or anything else. But when we go on to consider transverse axis instability we are confronted by numerous difficulties. As already shown this form of instability cannot be due to ascending currents. In the absence of evidence it is possible to conceive it being caused by variations of the speed of the wind. If a cheel gliding up-wind was to glide into an area in which the wind had a higher velocity then there would be a tendency for the centre of effort of the wings to move forward. It is conceivable that this tendency should cause the bird to tip up round the transverse axis. As a matter of fact the bird combats this form of instability by movements which must tend to move backwards the centre of effort of the wings. That is to say, in the absence of evidence, variations in wind velocity may be regarded as a possible cause of tail-jolting. But why is it that other forms of instability are so rarely observed in a tail-jolting wind? If tail-jolting is due to variations in wind velocity why is it that the bird has to tail-jolt to an apparently equal degree in whatever direction it is travelling relatively to the wind? Why is it that in a tail-jolting wind the assumed variations in wind velocity always affect both wings to an equal degree? Why should tail-jolting often be, so far as can be seen, greater at a height than at low levels, while wind variations are greater at low levels and less at a height? The connection just mentioned between transverse axis instability and soarability in stormy winds

indicates a line of study that may throw some light on the nature of the process by which sun energy becomes available for soaring flight. This preliminary discussion serves to show the importance of the subject. I now propose to return to the facts of the case.

The following additional instances show a connection between gain of height and tail-jolting :

15th March, 1912. At 4.5.—A cheel showed several small tail-jolts and a small double dip. Immediately afterwards it made a gain of height. Wind moving small branches. Some cirrus. Air clear.

This cheel glided from air in which it was steady into a path of air in which it tail-jolted, and passed from this into air in which it gained height. The following are similar cases :

24th April, 1912. At 3.15.—A dust-storm passing away. Dust thin. Sunshine. A cheel showed two successive tail-jolts just before a gain of height.

6th May, 1912. At 6.42 a.m.—Wind soarability. A cheel gliding up-wind near showed occasional gain of height and slight tail-jolting. Secondaries were not relaxed.

7th June, 1912. At 4.22.—Dust-storm. Low degree of soarability. Flight steady except occasional slight single-wing depressions.

4.42.—Wind moving small branches. Cheels now gliding up-wind making speed over the earth. A cheel showed double dips just before a gain of height.

It is a general rule that tail-jolting does not occur in the presence of other forms of soarability. Partial exceptions to this rule have been described as occurring in dust-storms. But in such cases, transverse axis instability generally occurs in gusts in which there is evidence of more soarability, while the other forms of instability occur in the absence of gusts and are associated with less soarability.

Another exception to the rule consists in the fact that sometimes in winds in which birds show lateral and dorso-ventral axis instability, transverse axis instability is shown instead when a bird is gliding down towards

the end of a glide. That is to say, the change in stability occurs at a moment when the bird is likely to be advancing the position of the centre of effort of the wings to check speed. I have only noticed this on four occasions.

In the following exceptional cases tail-jolting and other forms of instability occurred together :

9th April, 1911. At 4.0.—Dusty stormy wind. A black vulture at 200 metres height, fast flex-gliding up-wind, showed slow dorso-ventral axis oscillations of small amplitude, slight single-wing depressions, and tail-jolting.

15th May, 1912. At 1.50.—Strong dusty west wind, moving branches. A group of cheels and a scavenger at 50 to 100 metres height were gliding up-wind with wings slightly flexed, and showed both single-wing depressions and strong double dips at intervals.

14th May, 1912. At 8.45 a.m.—Wind moving small branches. Cheels were showing tail-jolting and single-wing depressions.

I have elsewhere stated that during the morning development of soarability, especially if wind soarability is present, different kinds of instability appear in succession. Usually tail-jolting, if it occurs at all, is the last to appear. Rarely also in the evening as soarability is dying away, the different kinds of instability may be seen together, but in this case tail-jolting is usually seen at a height, and other kinds of instability at lower levels.

But as a general rule, a tail-jolting wind is a wind in which birds are free of other kinds of instability.

It is often possible to see a connection between gusts of wind and transverse axis instability. That is to say, in a comparative calm birds fly steadily, but during a gust of wind tail-jolting is observed. For instance :

22nd September, 1911. At 10.3.—Wind north-west, moving leaves.

10.4 and 10.6.—Wind less. Cheels in steady flight. Then a cheel passed to windward of me, flex-gliding to east. It showed slight tail-jolting. Thirty seconds later wind was moving leaves, and one minute later it was moving small branches in a small gust.

10.25.—Puff of wind, moving small branches. Two cheels tail-jolting.

10.37.—Cheel flex-gliding beam on to wind steady. Wind had dropped.

10.38.—A cheel tail-jolting. Ten seconds after it passed me (to windward), a puff of wind.

I have recorded numerous similar instances of coincidence of tail-jolting with puffs of wind. In a few cases I have recorded tail-jolting in the apparent absence of wind, or when the leaves in the neighbourhood were only slightly moving. It may be the case that in such cases the cheel was present in a puff of wind too small to be noticed. For instance :

22nd October, 1911. At 3.30.—Calm. Cheels steady.

4.10.—Cheel at 50 metres height flex-gliding showed slight tail-jolting. Wind shown to be west by smoke, which was moving very slowly.

10th June, 1912. At 2.0.—Scavenger at 50 metres height flex-gliding showed tail-jolting. Leaves near still.

Most of my records of tail-jolting in apparent calm have been made in October, in which month the wind velocity is usually very low. If tail-jolting can occur on calm days, when smoke rises to a great height without sign of wind, then tail-jolting cannot be explained by such variations in wind velocity as are recorded by an anemometer.

But wind is not the only factor involved. For instance :

15th April, 1912. At 2.0.—Wind strong, occasionally moving branches. No tail-jolting. Cheels nearly steady.

16th April, 1912. At 1.42.—Wind slightly moving leaves. Cheels showing large tail-jolts.

The idea that tail-jolts in an apparent calm were produced by undiscovered wind-gusts does not harmonise with the following facts :

During the first thirteen days of April 1912, I noticed cheels in steady flight on five different days. On five other days I noticed tail-jolting in connection with wind puffs. From the 14th April to the end of the month I only noticed cheels in steady flight on one occasion. On nine other days in this latter half of the month I observed tail-jolting, but failed in every case to see any connection between it and wind-gusts. That

is to say towards the end of the month tail-jolting seemed to be continuous and to have no relation to wind-gusts. On the 3rd June I noted that "during the recent hot weather tail-jolting seems to occur daily."

Tail-jolting occurs more often, and to a greater degree, in hot than in cold weather, as shown by the following statistics :

In October 1911, the daily maximum shade temperature varied between 97° and 88° F. During this month steady flight was observed on fourteen different days. On twelve days tail-jolting occurred—on four occasions in apparent calm, on four occasions connected with wind-gusts, and on four occasions in wind.

In November 1911, the daily maximum shade temperature varied between 91° and 70° F. Steady flight was observed on seventeen days. Slight tail-jolting was observed in wind on three occasions. Strong tail-jolting was seen once in a dust-storm.

In March 1912, the shade temperature varied between 82.5° and 102° F. Steady flight was observed on nine days, and tail-jolting on nine days. Of these, on two occasions strong tail-jolting was observed in wind-gusts, and on six occasions slight tail-jolting, and on one occasion strong tail-jolting in wind.

In April 1912, the daily maximum shade temperatures varied between 92° and 108° F. Steady flight was observed on six different days, all of which occurred in the first (and cooler) half of the month. Tail-jolting was seen in connection with wind-gusts on five occasions, and in wind without obvious connection with gusts on ten occasions. Only in one instance during this month was it noted that the tail-jolting observed was slight.

If transverse axis instability is due to ascending currents one would expect it to be less as speed increases. The bird gliding at higher speed would be exposed for a lesser time to the disturbing action of the ascending current and hence would be less likely to be affected. But the following facts show that transverse axis instability is greater at higher speed and less at lower speed.

The speed of gliding through the air is, as a rule, less in circling than in other forms of soaring flight. Tail-jolting is very rarely observed in circling. One case was mentioned, at the beginning of this chapter, in which a bird circling in a stormy wind showed tail-jolting. In this case the bird, as it showed little or no leeward drift, must have been gliding through the air at unusually high speed on the windward side of the circle. Another instance of tail-jolting in circling is the following:

26th June, 1912. At 1.0.—A cluster of cheels circling. They often glided upwards unusually steeply. On the windward side of the circle a cheel was seen gliding upwards at an angle of at least 30° with the horizon. While so doing, it gained 2 or 3 metres height. Then on the down-wind side it glided horizontally with no appreciable change of speed, and on the leeward side of the track it made another similar glide upwards. This was seen several times. The cheels were tail-jolting. I could not see whether the tail-jolting was greater during a gain of height. Wind between me and the cheels was moving leaves in a gust. Two minutes later a dust devil seen near. Maximum shade temperature during the day, 112° F.

That is to say, in this case, tail-jolting in circling was seen in the presence of an unusually high degree of soarability.

With one doubtful exception I have not seen tail-jolting in carpal descent. In this form of descent speed ahead decreases. On the other hand I have on several occasions seen tail-jolting in shoulder descent. In this form of descent speed is high and increasing.

In stormy winds birds often glide through the air at much higher speed than in fine weather. The wing disposition may be the same in both cases. Tail-jolting is more often shown in the former case.

In flap-gliding flight speed increases during the period of flapping and decreases during the period of gliding. That is to say speed is highest at the moment that flapping ceases. It will be of interest to examine the forms of instability shown at this moment. In the following two exceptional cases a high degree of transverse axis instability was seen at the moment that flapping ceased, while the bird was steady during the remaining part of the glide :

23rd May, 1911. At 7.47.—A cheel flap-circling. On several occasions, at the end of a period of flapping, it rotated upwards round the transverse axis, and corrected this rotation by a double dip. Sun soarability commenced at 7.57.

27th July, 1911. At Bombay at 7.0 a.m.—Cheels commencing to circle. They flapped at intervals. Several showed tipping up round the transverse axis at the end of each period of flapping. In each case the tipping up was followed by a slight double dip. Weather fine. South wind moving leaves.

7.2.—No tipping-up seen. Several cheels observed.

7.26.—Cheels circling, but flapping to go up-wind.

In each of these two cases the tipping-up consisted of the bird suddenly rotating round its transverse axis until its angle of incidence was about 20° . The phenomenon was quite easy to observe.¹

In view of the fact that transverse axis instability is generally associated with a high degree of soarability one would expect it to occur but rarely while soarability is developing. On the other hand one might expect lateral instability to be shown more often at this time.

¹ At the beginning of the monsoon season swarms of winged white ants are met with in Agra. Cheels when catching these insects aim, while flapping, at the insect, then cease flapping, then turn upwards suddenly round the transverse axis, and catch the insect in their claws. This rotation round the transverse axis differs from that described in the text in that (1) it does not occur immediately but at a short interval (a fraction of a second) after flapping, (2) it occurs while the bird is on an irregular course, (3) it occurs only in the presence of insects, and (4) it occurs in the absence of any signs of soarability in some cases.

The facts correspond to this expectation. Occasionally a slight degree of lateral instability occurs immediately after flapping. This is very difficult to observe. Sometimes no instability is seen during the rest of the glide. Sometimes lateral instability is shown also in addition to the slight lateral jolt after flapping. In the following unique case signs of transverse axis instability were seen in addition :

29th May, 1912. At 7.20.—Wind west, moving small branches. Air thick.

7.29.—An eagle flap-gliding. After flapping it showed slight lateral instability. Then on the next occasion, after flapping, it showed slight lateral instability and a single upward jolt of the tail.

7.46.—Scavenger flap-gliding showed lateral instability after flapping, and then slight single-wing depressions.

8.1.—Sun soarability commenced.

8.3.—Cheel flap-gliding steady.

In view of the facts now brought forward one might expect that more transverse axis instability would be seen in fast than in slow flex-gliding. I have no evidence bearing on this point. Fast flex-gliding usually occurs at a height too great for tail-jolting to be seen should it occur. Further, on referring to the description of the position of the “pull” and the “drag” in fast flex-gliding, given in Chapter XI., it is by no means certain that the cause of tail-jolting, whatever it may be, could cause so great an effect with the wing disposition of fast flex-gliding as it can do with the wings in the slow flex-gliding position.

I have now to describe a form of rotation round the transverse axis which possibly is of a different nature from that associated with tail-jolting.

It has been proved that birds have two methods of rotating round the transverse axis. Firstly, by advancing or retiring the wings a rotation is produced

that causes a change in the angle of incidence and no change of course. This is seen in "stop descent." Secondly, by varying the dihedral angle of the wings a rotation is produced that changes the course but that produces no known change of the angle of incidence. In the first case rotation must take place round an axis that lies somewhere between the centre of gravity and the centre of effort of the wings. In the second case the rotation must take place round an axis that lies at some distance away from these points, perhaps some distance away from the bird.

Obviously it is possible that two kinds of transverse axis instability may exist corresponding to these two kinds of transverse axis rotations. This possibility is one reason why I have preferred the term "transverse axis instability" instead of the term "longitudinal instability," as used by aviators.

Possibly the following are instances of transverse axis instability of the second kind:

17th September, 1910. At 4.30.—Heavy cloud and stormy soarable wind from the east. Cheels wind facing and gliding up-wind. Often a cheel suddenly glided in an upward direction, and at the same time rotated round its transverse axis—that is to say, it became abnormally tilted up. Thereupon it rotated on its dorso-ventral axis through a right angle, and in this way became canted, and continued gliding, but at right angles to its former course. This "wind canting" appears to be a method of dealing with a puff of wind in soarable air. Is it possible that the object of circling is the same as that of wind-canting, namely, to avoid excessive tipping up round the transverse axis?

30th September, 1910. At 8.15.—A shower just over, and wind moving branches. No cheels up.

8.20.—Glare. Twenty-nine cheels up lee-looping or skimming over tree-tops with wind canting.

8.25.—Cheels were gliding to leeward, as in lee-looping. Then, on turning, they travelled up-wind with swerving. At length they showed strong wind-canting, and turned off to leeward. At the turn at the leeward end of their track, the canting was much less than that seen at the windward end. There was not, as a rule, leeward drift in this irregular circling. Occasionally gain to windward took place.

1st October, 1910. At 7.0.—Stormy wind, moving smaller branches. Heavy cloud. No glare. Cheels lee-looping.

7.35.—In wind-canting the upper wing seems to yield to the wind pressure.

9.0.—Occasional slight sunshine. Cheels circling and wind-facing. Wind-canting noted to be preceded by lift.

29th November, 1910. At 2.55.—A dusty strong west wind. Sky cloudless. Low level flapping beginning.

3.0.—Position of an ascending current noticed where the wind was deflected upwards by a large tree. A cheel several times glided into this current. Whenever it did so it was lifted; it was then rotated round dorso-ventral axis, becoming thereby canted, and then glided off to leeward.

The last-mentioned is the only case in which, in my notes, wind-canting was associated with the presence of an ascending current.

Though I have inserted these examples of wind-canting at this place it is by no means certain that they furnish a case of transverse axis instability. It is possible, and perhaps probable, that the dorso-ventral axis rotation is due to a voluntary adjustment. It is also possible that the gliding upwards that preceded it was also of voluntary origin. In Calcutta I have on several occasions observed wind-canting in cases in which the wind had the same speed as the speed of the cheel through the air, that is in cases in which the cheel showed a vertical gain of height while wind-facing. This suggests that wind-canting may be an appearance caused by a sort of shortening of the wind-facing period of lee-looping due to the speed of the wind.

There can be no doubt that the most important fact described in this chapter is the rarity of transverse axis instability being associated with lateral instability. If these two kinds of instability occurred commonly together, then it is obvious that they might be explained as being due to ascending currents, or horizontal pulsations, or some other pre-existing forms of air motion

that in one case affected one wing and in the other case affected both wings equally. But the fact that transverse axis instability usually occurs in the complete absence of other forms of instability excludes this simple explanation. How is it possible that in a "tail-jolting" wind any forms of pre-existing air irregularity should always happen to affect both wings simultaneously and to an equal extent? The only alternative view is that we are not dealing with pre-existing air movements, but with air movements that come into existence as a result of the motion of the bird. It would appear that at intervals, in a tail-jolting wind, air energy becomes available at a greater rate than that normal for the particular wing disposition, and that this is the cause of the advancing of the centre of effort of the wings that the tail-jolting movements are employed to combat.

CHAPTER XVIII.

COLOUR PHENOMENA IN SOARING FLIGHT.

We have attempted by the study of instability to throw some light on the nature of soarability. There is another method by which the problem may be attacked, namely, by the study of any physical phenomena that may accompany the taking of energy from the air by the bird. For instance a loud whirring sound is made by the wings of vultures when they are gliding in soarable air. I have as yet failed to hear a similar sound when they are gliding in unsoarable air. But I have no proof that the presence or absence of this sound has to do with the presence or absence of soarability. It is only in exceptional circumstances that vultures circle so near to the observer that this sound can be heard. I have no sufficient proof that a similar number of vultures gliding in unsoarable air at the same speed would not also make a whirring sound.¹ The opportunities of observation are so few that the subject is apparently not suitable for study from the present point of view.

On the other hand the Common Vulture and the White Scavenger Vulture show very curious colour changes when gliding in soarable air. I must preface my account of these colour changes by a confession of failure in so far that in the present state of our knowledge no reason can be adduced why such colour changes should be associated with soarability. I can merely state and, in the sequel, prove that such is the case.

¹ See a further reference to sound made in soaring flight in Chapter XIX., page 357.

The underside of the wing of the Common Vulture may be roughly described as being white with a black hind margin and black wing-tips. A similar description applies to the wing of the Scavenger Vulture, except that the white area is of larger extent.

On a fine day, whether in Agra, Futteypur-Sikri, or Naini Tal (with exceptions to be described later), the white part of the underside of the wing appears of a bright strong yellow colour in either of these species of vulture, both when circling and flex-gliding. A ruff of white feathers round the neck of the Common Vulture is white, and appears white under all conditions. The margin of the white tail of the Scavenger Vulture is somewhat translucent, and the sunlight shining through it gives it a white appearance.

The obvious explanation of the yellow colour is that it is due to reflection. The white feathers of the vulture are all of a pure snow-white colour; every one of the feathers is of the same pure white. So far as I am aware there is no yellow colour about the vulture anywhere. The soil in Agra is sterile during most of the year and has a yellowish colour. Frequently at least much yellow dust is floating in the air. Under the fierce Indian sun much yellow light must be reflected from this dust. Under these circumstances it is not surprising if the underside of the wing of the circling vulture appears yellow.

But, as generally happens in the study of soaring flight, the simple and obvious explanation is found on further study to be insufficient. On investigating the matter a little more closely we at once come across facts that are very difficult to explain.

I have stated that the underside of the wing of the vulture, at first glance, appears white with a black hind margin. The white part consists of certain of the covert feathers. The black margin consists of the exposed portions of the secondary quill feathers. These feathers are really of a dark greyish-black or faded-black colour ; but the shafts of the quills are white.

On a fine day in the cold weather, when there is scarcely any perceptible wind, vultures at Jharna Nullah may occasionally circle overhead at a height of less than ten metres above the ground. When seen under such favourable conditions the white coverts may be seen each pressed firmly against the under surface of the wing and having a bright canary yellow colour. The colour is quite conspicuous and easy to see. The appearance is as if a strong yellow light was illuminating the underside of the wing. The shafts of the primary quills also appear yellow, and the vanes of the secondary and the basal part of the vanes of the primary quills also appear to be reflecting yellow light. The secondary quill feathers have a dull yellow or yellowish-black appearance, except the free rounded ends for about $\frac{1}{2}$ in., which appear black. Hence the hinder edge of the wing appears to have a narrow black margin, which is generally only visible when the bird is a short distance away.

If we were simply dealing with a solid object reflecting yellow light it is by no means clear why the tips of the secondary quills should appear black, for as will soon be apparent, a difference of inclination cannot be called in as an explanation. The yellow appearance of the shafts of the primary quills is a proof that the colour is not due to seeing the covert feathers at some unusual angle or to light being transmitted through the struc-

ture of the wing, suggestions which are improbable on other grounds.

When seen under favourable conditions the next fact that attracts attention is that when circling the inside wing has a slightly darker yellow tint than the outside wing. If a flush of colour suddenly spreads over the outside wing, so that the yellow of the two wings becomes equal, then it will be found that the bird is changing its course. It will be seen to be circling in the other direction. The other wing has now become the outside wing, and soon acquires the lighter colour. That the difference of tint of the two wings is not due to the bird being canted will be shown in a later paragraph.

The facts that I have to bring forward relating to colour will be found not only to be perplexing in themselves but also to point to contradictory conclusions. It will be advisable to state briefly what I propose to attempt to show.

Firstly I shall bring forward facts that tend to prove that the colour is due to reflection, as might be expected, but that, as would not be expected, the wing only has the power of reflecting colour so long as it is taking energy from the air, and that the depth of colour is proportional to the rate at which air energy is being used.

Secondly other facts will be quoted that tend to show that the colour is not due to reflection.

Thirdly under certain atmospheric conditions not yet defined, colour appears to be due to reflection, and to have no relation to rate of absorption of energy, but to be related simply to speed ahead through the air. That is to say under these conditions the wing reflects

colour so long as the bird has speed ahead irrespective of whether or not it is taking energy from the air.

Fourthly I have also to discuss cases in which colour is almost or quite absent, perhaps owing to glare of light reflected from clouds, etc., or low degree of soarability of the air, although conditions appeared suitable for reflection to occur.

As an example of facts tending to prove that colour is due to reflection, the following observations may be quoted, which were carried out in Naini Tal. The vultures were gliding not over yellow soil as in Agra, but for the most part over green vegetation, and their wings showed not yellow, but a green tint :

23rd June, 1911, at Ballia Ravine. At 9.45.—A vulture ease-gliding. Wings appeared greenish. It made a double dip, and changed to flex-gliding. The green tint deepened. A cluster of vultures were near the slaughterhouse, probably attracted by food. Those in carpal and metacarpal descent appeared white. Those ease-gliding appeared greenish-white. The difference was distinct, and seen in all that could be observed. One vulture, after descent from a height at higher speed than usual, showed white, except that the centrally placed covert feathers appeared yellowish-green. A vulture in metacarpal descent, and appearing white, changed to ease-gliding, and appeared greenish-white. There was much glare, many clouds, and the birds were only infrequently seen on a blue sky background. The green colour usually was a pale grey green, and occasionally pale yellowish-green when passing over rock. In one case, in sunshine, a vulture appeared pale bright green. On two occasions vultures circling showed inside wing of deeper tint.

In the case of the cluster of vultures near the slaughterhouse, there can be no question that they were all observed under the same conditions of background (the Sher-ka Danda Mountain) and illumination. The case seems clearly one of colour due to reflection, and so far as it goes, shows that the power of reflecting colour is only possessed so long as the birds are taking energy from soarable air. But on continuing my observations contradictory facts were elicited. At the time of making the above observations the weather was

showery and the air damp. During the following few days the weather cleared up. This was accompanied by a change in the appearance of the vultures. They appeared yellowish-green when near, and yellow when seen at a distance. The vegetation retained its bright green hue. There was no appreciable quantity of dust in the air that might be invoked to explain the yellow colour. But in spite of the change of tint, there was the same relation of depth of colour to energy consumption as before. For instance :

30th June, 1911, at Ballia Ravine. At 12.30.—A vulture in descent. Wings were flexed, but it was keeping up speed ahead through the air. Its feet were dropped. This was "shoulder descent." It appeared yellow. Then it dropped its legs (an indication of a change to carpal descent), and for two circles appeared white. Then it settled.

12.47.—A vulture circling, and appearing yellow, changed to metacarpal descent, and appeared white. Then it changed to ease-gliding, appearing yellow. Then it again turned white, and was seen to be in metacarpal descent with feet dropped. Then it drew up its feet, and appeared yellow. Then it made a double dip, and changed to fast flex-gliding. The colour thereupon changed to darker yellow, with a faint greenish tinge.

12.50.—A vulture descending in a strong wind appeared yellow. Its feet were dropped. It then dropped its legs, and appeared white.

12.53.—A vulture in descent appeared yellow. Then it turned white for about a second. Then yellow for two seconds. Then it turned white, and settled. Wing-tips were seen to be retired, but slightly turned up.

12.57.—A vulture ease-gliding at a distance appeared yellow. When near me it appeared yellowish-green.

1.22.—A vulture, appearing pale yellow, increased flexing of wings, and appeared of a darker yellow colour. It was in shoulder descent, and gliding steeply downwards with speed ahead. Wing-tips were slightly turned up. It turned white just before settling.

1.30.—A vulture high up and nearly overhead, on blue sky background, had legs dropped, wings flexed, and appeared white. Then it turned faint yellow, and then again white. It remained white both on blue sky and green mountain background, and settled. This was in light wind.

In the above observations so long as the wind was strong, vultures gliding against it had but little need to check their speed ahead through the air as they had but little speed ahead over the earth. Hence they

came down by shoulder descent, *i.e.*, maintaining the angle of incidence, and showing colour. When the wind dropped, a vulture in descent had occasion to check speed ahead through the air (in order to reduce speed ahead relatively to the earth). Hence it ceased to use air energy, and glided for a long distance, presumably in metacarpal descent, and appearing white.

I have now to quote observations to show that vultures appear white when in metacarpal descent in Agra :

1st December, 1910, at Jharna Nullah. At 11.3.—A cluster of vultures circling appeared yellow. One was seen to be white. It was found to be in metacarpal descent.

4th December, 1910, at Jharna Nullah. At 11.45.—Three vultures in metacarpal descent appeared white. Circling vultures not in metacarpal descent were yellow.

11.52.—Five more vultures seen in metacarpal descent appeared white, except one which appeared pale yellow.

11.53.—A vulture in metacarpal descent appeared yellowish at first, then white when near the ground.

3.15.—At house. Vultures circling overhead at 600 metres height. They appeared yellow, as usual, the inside wing darker yellow.

It might be suggested that the change from yellow or green to white, in the above cases, was due to reflecting power diminishing as speed ahead decreases. That this is not the case is shown by the following cases in which the decrease of colour was seen to be instantaneous. Under the circumstances it is impossible that there could have been an instantaneous decrease of speed :

24th July, 1911, at Jharna Nullah. At 6.3 p.m.—Wind at ground level south-west, moving leaves only. Wind strong at a height.

6.18.—A vulture gliding downwards appeared pale orange yellow. Its wing-tips were turned up. Then it rotated its wing-tips so that they became flat, and at the same instant the colour became nearly white. The change of colour was sudden and striking. It then made a double dip, and dropped its legs. After doing this it was snow white. By this time it was near its perch, and settled.

These colour changes occurred within a space of, at most, twenty metres, while the bird was gliding

over an empty paved yard, and quite close to where I was standing :

5th August, 1911, at Jharna Nullah. At 5.50 p.m.—Strong wind.

6.0.—A vulture appearing pale yellow descending with speed ahead in wind with wings flexed. It increased the flexing of its wings and the steepness of its descent. But the wing-tips remained turned up, and there was no colour change. Then the bird turned, so that I could no longer see the underside of its wings. It then rotated the wing-tips down. About a second later it turned back to its original direction, so that I could again see the undersides of its wings. They appeared quite white.

26th August, 1911, at Jharna Nullah. At 5.35.—Wind dropped. Two vultures in descent appeared pale yellow. They flexed their wings, and at once appeared white. This happened when they were about 10 metres up. (The flexing must have been carpal, and not at the shoulder joint, because it was not followed by rotation round the transverse axis. Because it was carpal, the wing-tips must have been rotated down.)

22nd October, 1911, at Jharna Nullah. At 10.40.—Wind west, moving branches. A vulture settling with wings flexed. It increased the flexing of one wing, as if for a dropping turn. During the moment of this extra flexing, this wing appeared white. Otherwise the colour was yellow. A vulture showed decrease of colour at moment of rotating wing-tips down. A vulture descending with wings flexed, but with angle of incidence maintained, appeared coloured.¹ Then it appeared white after turning down wing-tips. A vulture showed decrease of colour at moment of decrease of angle of incidence. On the other hand, the majority of vultures were descending hurriedly on to carrion with wings flexed and tips up, and hence showed no colour change till moment of stop-flapping.

31st October, 1911, at Jharna Nullah. At 11.0.—A vulture appeared yellow. Then it put its wing-tips flat, and appeared white. Then it flexed its wings, and increased its angle of incidence and regained its yellow colour. This was "carpal descent" combined with "stop descent."

I have elsewhere shown that one of the functions of the wing-tips is to maintain the angle of incidence in soarable air. As long as the angle of incidence is maintained energy is being taken from the air. Energy is no longer being taken from the air, *qua* soaring, as soon as, by rotation downwards of the wing-tips, the angle of incidence is abolished or diminished while camber is maintained. The decrease of the angle of incidence in

¹ It may be well to explain that this description represents what I wrote down in my notes at the time. I was writing hurriedly. It took less time for me to write "wings flexed but with angle of incidence maintained" than for me first to realise and then write "shoulder descent." Recently (July, 1912) I noticed some vultures collecting over carrion. After diving they first checked their dive when at about 100 metres up. Then they circled, appearing white (probably with wings flexed at metacarpal joint), presumably until then had checked speed ahead. Then they descended rapidly, appearing yellow. This was probably shoulder descent or shoulder combined with carpal descent. But the conditions for observation were not good, and I only saw the colour in two or three birds.

the above cases was instantaneous. The change of colour was instantaneous. Any change of speed ahead can only have been gradual. Therefore we can say that, in the above cases the colour change was connected with the change of rate of using air energy and was not connected with change of speed. I may explain that my discovery of the function of the wing-tips in maintaining the angle of incidence was made by noting the above-described colour changes. Though it would be premature to attempt to explain these colour changes, it is not premature to use colour change in getting some further insight into the nature of soaring flight.

In the preceding paragraphs I have shown that colour decreases on change to metacarpal descent *pari passu* with decrease in the use of air energy. I have now to show that colour increases on the change from slow to fast flex-gliding *pari passu* with the increase in use of air energy. Thus a further proof will be obtained of a connection between depth of colour and rate of use of air energy in soaring flight.

In circling the colour is usually bright chrome yellow. The colour may be compared to that of a canary. In slow flex-gliding the colour is the same except that both wings have the same depth of colour. In fast flex-gliding the colour is markedly deeper. On a background of blue sky it may appear as an ochre yellow. The colour usually appears at least as deep (though not perhaps of exactly the same tint) as the rind of a ripe pineapple. If the change from slow to fast flex-gliding is initiated by means of a double-dip the colour change may occur as a sudden flush. In certain cases there is the appearance of a latent interval between the double-dip and the resulting colour flush.

22nd November, 1910. At 3.5.—A vulture ease-circling. It made a double dip, and began flex-gliding. It appeared to get yellower about 2 seconds after the double dip.

6th December, 1910.—A similar observation.

7th December, 1910. At 4.0.—A vulture circling showed inside wing darker. It made a double dip, and commenced flex-gliding. There was an interval between this and the lighter (outside) wing acquiring a darker shade. The darkening of tint came on suddenly, at least as quickly as the double dip.

18th December, 1910, at Jharna Nullah. At 11.8.—A vulture slow flex-gliding made a double dip. The increased depth of colour was almost instantaneous.

11.32.—A vulture slow flex-gliding made a double dip. The increase of colour appeared after about a second.

11.55.—A vulture slow flex-gliding made a double dip. The increase of colour occurred $3\frac{1}{10}$ secs. later.

I suspect that this abnormally long latent interval between the double-dip and the flush, in the last observation, was due to the fact of my being fatigued at the time. On another occasion I recorded a latent interval of two and a half seconds, and also noted that I felt fatigued (29th December, 1910). Holding a stop-watch and a binocular at the same time is not a satisfactory condition for observing. Pressing the release of the stop-watch gives a jerk to the binocular interfering with accurate vision. Hence I am more confident as regards observations made without a stop-watch and showing a short latent period without attempt to estimate its duration. For instance :

29th March, 1912. At 1.6.—Air very clear. No dust. Wind west, leaves still. A vulture flex-gliding at 400 metres height showed a colour flush at a short interval after a double dip. The secondaries were of faded yellowish black colour, except at the free ends, which appeared black for about half an inch. Colours in this and other vultures were visible perhaps unusually deeply for the time of year.

3.27.—A strong wind, very gusty, moving branches, had just risen, and dust was rising here and there. Difference of colour of the wings of circling vultures only visible with difficulty.

The above observation illustrates the fact that the presence of dust in the air greatly interferes with colour appearances. Also it is an example of an observation

of a colour flush being seen under favourable circumstances. Had I been fatigued I should probably have omitted to record the appearance of the last $\frac{1}{2}$ in. of the tips of the feathers in a vulture at 400 metres distance.

The power of showing colour is not directly connected with the pressure, as such, of the air on the surface of the wing, for the following reasons. I have elsewhere shown that in fast flex-gliding the air pressure is exerted at right angles to the surface of the wing. In fast flex-gliding where energy is being taken from the air the colour is dark yellow. In stop-flapping the air pressure is also exerted at right angles to the surface. In this case energy is being given to the air and the colour is white with an exception to be mentioned later. The difference in the two cases is not due to the wing being held still in one case and being flapped in the other, because when flapping in soarable air the colour also is yellow, as shown by the following observation :

8th February, 1911. At 5.27.—A vulture flap-circling at 80 metres height. It appeared yellow, and the inside wing appeared yellower during the flapping, apparently both during the up-and-down strokes. Vultures at higher levels were circling without flapping. Wind north-west, moving leaves.

This vulture would not have attempted to circle unless the air had had a certain degree of soarability. Usually in flap-gliding flight in unsoarable air vultures appear white in the absence of sunset colours. For instance :

28th August, 1911, at Jharna Nullah. At 5.2.—A vulture flap-gliding. A slight increase of the angle of incidence seen during the glides. Vultures flap-gliding appeared slightly yellow. Yellow light was shining out from between clouds to the west. A few minutes later this ceased, and flap-gliding vultures appeared white.

I now propose to bring forward certain facts that appear to indicate that the colour that has been shown

to be related to employment of air energy is not due to reflection.

Firstly if colour is due to reflection of light from the yellow soil and from yellow dust floating in the air the colour should be more visible when there is more dust and *vice versa*. But the contrary is the case. For instance :

19th April, 1912. At 9.10.—A vulture circling overhead at 40 metres height showed pale colour. The inside wing was darker. The black border of the hind margin of the wing could be distinguished. It made a double dip, and immediately afterwards both wings showed a slightly darker and equal yellow tint. There was much dust haze in the air. Wind east, slightly moving leaves.

On the other hand, in bright intervals during the rainy season in Agra, when the surface of the earth is green, and when there is no appreciable amount of dust in the air, the colour shown is usually yellow, and is very clearly and strongly shown. For instance :

25th August, 1911. At 3.27.—A vulture at 400 metres height made a double dip. The colour flush appeared after an interval. A scavenger circling overhead appeared dazzlingly bright yellow. Leaves still. Drift of circling birds indicated that wind at a height was from the west. Bright sunshine and small cumulus clouds travelling slowly from west.

3.35.—An adjutant circling. Its body (which really is white) appeared yellow. A vulture circling appeared dazzlingly bright yellow. The inner wing was darker. It then showed a darker tint on flex-gliding.

Secondly the view that colour is due to reflection appears to be negatived by the fact that in certain cases, in not fully soarable air, the colour is not yellow, but pink. I have noticed this on more than twelve different occasions. The colour is generally a pale greyish-pink. Sometimes I have noted that the colour appeared pinkish-yellow. It is curious that as a rule on these occasions the impression of pale orange was not produced. The following are examples of pink colour :

1st December, 1910, at Jharna Nullah.—Wind imperceptible. Haze.
9.30.—Cheels began circling.

9.54.—A scavenger circling appeared pink. A vulture flap-gliding appeared white.

10.2.—A scavenger circling appeared yellow.

10.3.—A vulture flap-circling appeared pink.

10.6.—A vulture flap-circling appeared yellow.

11.40.—Vultures circling at low levels occasionally flapped at intervals, and appeared pink. There was much dust at a height in the air. Soarability was not high. For instance, during the time of observation, no adjutant made any attempt to circle. Two or three were seen flap-gliding for short distances.

30th December, 1910. At 9.43.—Circling of cheels began. Wind south-east, moving leaves.

11.6.—Vultures circling. They appeared orange-yellow.

11.16.—A vulture flap-gliding at low level, perhaps 80 metres, appeared pinkish white. It was going towards the Fort, travelling to north-west. Then it turned and came back over the same course, going in a south-easterly direction. It showed the same colour. Then suddenly, while still flap-gliding, it appeared pale orange-yellow. Then it began circling, appearing pale yellow with a slight orange tint. Its wings were not advanced.

11.39.—Vultures were circling with wings slightly advanced, and appeared strongly yellow.

3.50.—Slight cirro-cumulus cloud, but some sunshine. A vulture slow flex-gliding in the direction of Jharna Nullah appeared pale yellow. Suddenly it rocked on its longitudinal axis. At this moment the colour deepened, and its speed was seen to be increased. (Apparently it had reached a patch of more soarable air. Probably one wing reached this more soarable air before the other, thus producing the observed lateral instability.)

23rd July, 1911, at Jharna Nullah. At 8.25.—Circling of vultures beginning.

8.30.—The yellow colour of circling vultures had an orange rather than a greenish tint.

8.50.—A scavenger near, on commencing descent, appeared pinkish yellow.

8.55.—A vulture ease-gliding appeared yellow. Then it turned pinkish yellow. Then it dropped feet, and appeared of a paler tint. Then it dropped legs, turned white, and settled.

8th August, 1911, at Jharna Nullah. At 5.50.—Vultures coming down in a strong wind by shoulder descent. They showed no colour change till moment of perching, when they turned white, except that when at a height they were grey-yellow, and when they got into less soarable air near the ground they showed a pinkish tinge.

6.5.—The air at low levels appeared to become unsoarable rather suddenly. Scavengers now in flap-gliding flight, and appeared white.

21st August, 1911, at Jharna Nullah. At 6.5.—Vultures at 300 metres slow flex-gliding showed a pinkish colour. Low level soarability had ceased.

2nd April, 1912. At 8.38.—A vulture starting. It was flap-gliding, and appeared pink. Two minutes later it was yellow, and circling. It showed no lateral instability.

The foregoing observations have been made at different seasons of the year. The pink colour has been seen when the surface of the ground was of a pale yellowish-brown colour. It has also been seen in the monsoon season when the ground was covered with green vegetation. Besides the above-quoted cases in which it was seen between 11 and 12 o'clock, I have observed it at 2.55 p.m. That is to say, there are no grounds for connecting the pink appearance with sunrise or sunset colours.

If the colour thus varies in tint with the soarability of the air it is very difficult to believe that we are dealing merely with a case of reflection. We will now return to further description of the ordinary yellow colour.

I have previously stated that, in circling, the inside wing has usually a darker colour than the outside wing.¹ In circling the wings are, as a rule, slightly dihedrally-up, and the bird is canted over so that the inside wing is less inclined to the horizontal than the outside wing. It might be thought that the difference in tint is due to the wings being thus seen at a different inclination, the more horizontally placed wing being in a better position to reflect the colour of the soil. That this explanation is not correct is shown by the following facts. In circling the amount of canting is usually greatest on the windward side of the circle. It may be less or non-existent on the down-wind side of the circle. But the cases related on the following page show that on the up-wind and windward sides of the circle the colour difference of the two wings ceases to exist.

¹ If a cheel or a vulture has the primary feathers of one wing damaged or cut, it nearly always circles in such a direction that the intact wing is on the inside. This fact suggests that the inside wing takes more energy from the air than the outside wing, in correspondence with the difference of colour.

1st December, 1910, at Jharna Nullah. At 10.43. — A scavenger circling at 200 metres height to windward. The inside wing appeared yellower, and both wings had the same tint on the up-wind and windward sides. At the end of the downward side both wings appeared nearly white.

10.45.—The same colour changes seen in a scavenger circling at a small distance to leeward.

10th December, 1910. At 11.0.—Vultures flap-circling, then circling. One circling 100 metres overhead showed the inside wing darker. Several times the outside wing was seen to acquire an equally dark tint on the up-wind side of the circle. A double dip seen with instantaneous colour change.

16th December, 1910. At 3.57.—Vultures at a short distance overhead occasionally showed both wings equally dark at up-wind end of up-wind side of circle, or along windward side of circle.

19th September, 1911. At 3.50.—Wind north, moving small branches. Fine. A few thin clouds. Sunshine. Vultures pale yellow, showing the same tint for circling and flex-gliding. In one case, however, a slightly darker tint of inside wing distinguished with difficulty. On the windward side both wings had the same darker tint.

20th September, 1911. At 3.50.—Wind shown to be north by smoke. Cheels nearly steady. Vulture circling at 350 metres was pale yellow, but the inner wing appeared darker. Both wings equally dark on up-wind side. Colour slightly darker for flex-gliding both at 60 and 300 metres height.

11th April, 1912. At 5.17.—A vulture circling at 200 metres height. Colour difference of the two wings strongly marked. On up-wind side of circle both wings had the same tint. On the windward side the sun shone on the underside of the wings, and they appeared white. (With direct sunlight shining on the underside of the wings, no trace of colour is ever seen.)

28th March, 1912. At 4.37.—A scavenger circling at 500 metres showed inside wing darker than outside wing on down-wind and leeward sides of track only. On the up-wind side both wings were equally dark yellow. It was drifting slowly from the east. This colour difference was seen three or four times, both when the bird was to windward of me and when it was abeam. The difference of tint was not strongly marked.

I have elsewhere stated that in circling there is loss of speed on the windward side of the circle. Gain of height occurs especially on the up-wind and windward sides. It is of interest that more colour is shown at a time when the bird is gaining height, thus proving that colour is associated with use of air energy. Further, since the colour was more when the speed was less, it is not simply a power of reflecting consequent on the

wing surface being, so to speak, polished by gliding through the air.

But this loss of colour difference on the up-wind side in circling is not always shown. For instance :

22nd November, 1910. At 3.30.—A vulture showed inside wing of darker tint of yellow all round the circle.

4.0.—A vulture circling overhead showed the inner wing darker all round the circle, except on the down-wind side.

23rd November, 1911. At 3.35.—A vulture circling showed the inside wing darker yellow on up-wind side of circle only.

12th October, 1911. At 3.45.—Air very clear. Vultures circling at 800 metres. The inner wing clearly seen to be darker than outside wing, except on down-wind side of circle. Sunshine on underside of wings at beginning of this part of the circle.

16th September, 1911. At 4.10.—Fine. Wind west, moving leaves. Vultures circling at 800 metres showed wings of equal depth of colour.

It may be remarked that, besides circling with effort to gain height on the windward side circling without effort to gain height also occurs. Sometimes also there is a gain of height on the leeward side of the circle. The vulture is only well situated for observing colour differences when it is directly overhead. It often happens that the colour differences are not strongly marked. But, as a rule, an equal colouring is observed on the up-wind and windward sides of the circle, and the exceptions to this rule above described do not disprove the possibility that the colour change is in some way connected with change in rate of use of air energy.

I have elsewhere shown that if in circling the wings are advanced more energy is being taken from the air than is the case when wings are not advanced. I have observed colour differences in accordance with this rule. For instance :

16th December, 1910. At 3.30.—Wind east, moving leaves. A few isolated high level clouds. Sun shining. Vultures circling overhead. Wings rather pale yellow, and not advanced. One appeared to get yellower just before a double dip. Other vultures fast flex-gliding showed a full yellow colour.

3.32.—Vultures circling to north of me had wings advanced, and were full yellow.

3.45.—A vulture circling overhead had wings advanced and of full yellow colour.

3.46.—A vulture circling overhead made a dip of the outside wing. It instantly became yellower.

3.48.—A vulture circling changed to flex-gliding. No double dip was seen, but the sun shone for a moment on the underside of the wings, proving that there was a temporary rotation of the plane of the wings. The bird was going away from the sun, namely, to the east.

3.50.—A vulture seen circling overhead with the outside wing paler as usual. Suddenly a flush of colour came over this outside wing. Then it became apparent that the vulture was changing its direction. The flush of colour must have been the sign of a dip not otherwise visible. The wing that had been the inside wing became paler as usual when the direction of circling had been changed.

3.53.—This was again seen. The vultures were about 100 metres up overhead.

20th December, 1910. At 4.2.—A vulture overhead at 700 metres; wings pale yellow, and not advanced.

4.3.—A vulture overhead at 700 metres. Wings strongly yellow and advanced. Wind west, moving branches, and cold.

If colour, whether due to reflection or not, is in some way a sign that energy is being taken from the air, then we should expect colour in diving to be white. The following observations may be quoted :

25th January, 1911. At 3.45.—A vulture circling under slight cloud shadow appeared yellow. It dived, and immediately appeared snow-white.

6th February, 1911. At 2.35.—Two scavengers ease-gliding and playing. They dived. Each at moment of dive turned suddenly white.

29th August, 1911. At 2.40.—Weather clearing up. Isolated cumulus clouds. A vulture circling in sunshine under a cloud appeared pale yellow, and yellower when seen on background of blue sky. It appeared paler when seen on background of brighter part of the cloud. The edges of the cumulus clouds were often ragged and shining with yellow light, which may explain the exceptionally strong yellow colour seen this afternoon.

4.5.—A vulture slow flex-gliding at 800 metres in sunshine appeared pale yellowish pink on cloud, and dark yellow on blue sky background. Then it placed its wing tips down, and appeared nearly white. Then, flexing its wings, it appeared quite white, and settled.

4.10.—A vulture on blue background appeared dark yellow.

4.20.—A vulture made a dive or swoop for a short distance, retaining its yellow appearance. (It is possible that this dive was shoulder descent with angle of incidence maintained.)

If much dust is present in the air colours are much paler than usual and colour changes on varying the mode of flight may be difficult to see or may be even invisible. In other rare cases, for no known reason, colours may be lighter than usual. For instance :

11th December, 1910, at Jharna Nullah. At 10.15.—One adjutant starting. Vultures and scavengers were of lighter colour than usual. Once or twice vultures when circling appeared nearly white, only showing a recognisable tint of the inside wing. There was a strong cold wind.

19th September, 1911. At 3.50.—Wind north, moving small branches. Fine. A few thin clouds. Sunshine. Vultures pale yellow. They showed the same tint when circling and flex-gliding. But in one case, in circling, the inside wing had a slightly deeper tint, except on the windward side, when both wings were equally tinted.

20th September, 1911. At 3.50.—Wind shown to be north by smoke. Cheels in nearly steady flight. Vulture circling at 350 metres was pale yellow, but the inside wing was darker. Both wings were darker on the up-wind side. Vultures appeared slightly darker yellow when flex-gliding both at 60 and at 300 metres height.

Thus we see that as a rule the depth of colour is an indication of the rate at which energy is being taken from the air. This fact is of a most puzzling nature. Now we have to describe exceptions, some of which I think will be found to be as puzzling as the rule.

When the sky is covered with isolated clouds there is often an intense glare of light. Under these conditions colours are often no longer visible, or not visible in their normal relations. For instance :

24th August, 1911. At 1.5.—Two vultures, about 200 metres up, flex-gliding up-wind towards a rain-storm, appeared yellow when seen on blue sky background. On cloud background they appeared nearly black. (This was a background of cloud having an intense white glare of light. As may be expected, under such conditions a less highly illuminated object, namely, the underside of the wing, appears black.)

1.10.—The same two vultures retreating before the advancing rain now appeared green.

1.15.—Rain shower passing about 300 metres to east.

2.30.—A scavenger just in front of rain, under heavy cloud, appeared white.

25th August, 1911. At 9.1.—A vulture at 500 metres height circling under cloud appeared white. Then it changed to slow flex-gliding, and appeared yellowish-green.

29th August, 1911. At 4.5.—A vulture slow flex-gliding at 300 metres in sunshine appeared pinkish-yellow on cloud, and dark yellow on blue sky background. Then it placed wing-tips down, and appeared nearly white. Then flexing its wings, it appeared quite white, and settled.

15th September, 1911. At 2.49.—A vulture circling appeared yellow on blue background. When it passed on to a background of very bright white cloud, it appeared faint greenish yellowish white.

2.50.—A vulture at 60 metres height flex-gliding appeared nearly white on cloud background, and yellow on blue background.

That this tendency for the yellow colour not to be visible on a bright cloud background is due to an optical effect is proved by the following fact: On two or three occasions I have noticed that the red and yellow colours of a rainbow were invisible on a bright white cloud background. These colours at the time were visible in another part of the rainbow that had a background either of blue sky or of less highly illuminated cloud.

In Agra, as in Naini Tal, the colour may be green, and not yellow in the close neighbourhood of cloud or rain. I have proofs that this green colour is due to reflection. For instance:

7th September, 1911. At 4.17.—Thunder, and very dark cloud to north. An extension of this cloud travelled in a southerly direction to west of me, shutting out sunshine here. The air then became unsoarable, and all birds settled. The attraction wind (*i.e.*, a wind blowing from the south towards the storm) was slightly moving leaves.

4.20.—Slight dust rising beyond the Fort (to north-west of me). The wind overhead was now from the north (*i.e.*, displacement wind). Some cranes were circling in it. The white parts of their wings had a slightly yellowish tint. This was possibly due to yellow glare of light that was now coming out from under the cloud mass to the west.

4.21.—The displacement wind could now be felt here. It first moved small, then large, branches. Many cheels, an eagle, and a vulture, were circling near in this wind. The vulture passed circling about 10 metres overhead. At first it appeared faintly green. Then, as it passed over the house (which is white-washed, with a white concrete roof) it appeared white. Cheels wind-facing were steady.

11th September, 1911. At 7.0.—Wind east, moving small branches. It had rained during the night. Wet-looking clouds were moving fast from the east. Patches of sunshine. Wind soarability, and cheels circling high. When gliding up-wind they were steady. Their wings were generally arched, and they showed slight loss of height.

7.20.—A scavenger gliding up-wind, with occasional flapping, appeared strongly green. It passed over the house at a height of 5 metres. While so doing it appeared white. This was on a cloud background. Its flight was steady.

7th March, 1912, at Firoz Khan's Tomb. At 5.15.—Leaves still. Wind apparently north-west. A vulture seen at a height. It appeared pale yellow. When descending, and about 15 metres from me, it appeared pale bright green. It was over a field of green barley. During the horizontal glide to perch, shaking of secondaries seen.

5.18.—A vulture descending appeared pale green. It showed digital quill gap twice over, for a moment, of outside wing during a turn. (This is exceptional. Probably the adjustment was intended to check the turning movement.)

The last-quoted observation is the first case I have brought forward of a green colour when gliding over a green object being seen in fine weather. More usually green colour is only observed in the immediate neighbourhood of cloud or rain.

I have brought forward facts that indicate that, as a rule, a loss of colour corresponds to decrease in rate of employment of air energy. I have now to mention cases in which there is no decrease of colour of this nature, but in which there are grounds for believing that the colour observed is due to reflection, and in these cases apparently the underside of the wing has the power of reflecting colour independently of energy consumption, and retains this power so long as there is speed ahead. The fact that there is a difference between these reflection colours and ordinary colours may be regarded as a proof that ordinary colours are not due to reflection. But though the facts to be described may seem to point to this conclusion, it would not be wise to accept any definite opinion in this very perplexing subject.

My friend, Dr. J. H. Marshall, tells me that on one occasion, while on a steamer in Aden Harbour, he noticed that the underside of the wings of gulls in

gliding flight had a blue colour. The colour, he tells me, was at least as deep as that of the Blue Jay, a common Indian bird. That is to say, the colour observed was a bright Cambridge blue. On three other occasions he has looked for this blue colour without seeing it. On several occasions I have watched gulls at Bombay, Aden, Port Said, and Suez, without seeing, in any case, any sign of blue colour. There can be little doubt that on the single occasion on which colour was observed it was a reflection of the blue colour of the sea; that is to say, on rare occasions, under unknown atmospheric conditions, the underside of the wings of gulls has the power of reflecting coloured light. Certain of the following cases appear to be of reflection of the colour of the ground over which vultures were gliding in Agra :

1st November, 1911, at Jharna Nullah. At 10.30.—A few small cumulus clouds. Sunshine. Vultures showed no colour changes in descent, except that they were yellow with a brownish tinge when near the earth, but had the usual chrome yellow tint when gliding at a height.

8th October, 1911, at Jharna Nullah. At 10.12.—A vulture ease-gliding with wing-tips up appeared yellow. Just before settling it rotated tips down, and appeared pale greenish-yellow. When settling, it appeared white. Two vultures descending with tips down appeared greenish-yellow. A vulture appeared slightly yellow when stop-flapping. This was again seen. (This observation of colour in stop-flapping is quite exceptional.)

10.47.—A vulture, about 10 metres up, appeared yellow. It flexed its wings without transverse axis rotation (= carpal descent), and appeared white. It again appeared yellow when about 1 metre up and in stop-flapping. Vultures descending with wing-tips up and wings flexed (shoulder descent) appeared to lose colour with speed only. During the period of observation the colour shown by vultures when near the ground was pale brownish yellow. The tint was quite different from the colour shown when gliding at a height.

30th September, 1911, at Jharna Nullah.

11.0.—Glare. Small rainy cumulus clouds. Cheels, vultures, and adjutants circling and flex-gliding. Cheels in steady flight. Wind west, moving leaves. Vultures pale yellow when at a height, and greenish when at low level. A vulture appearing yellow changed to carpal descent, and appeared green. This was within a few feet of a yard covered with green vegetation. Vultures, when descending over a bare courtyard having no vegetation, appeared yellow, and only turned white just at the

moment of perching—that is to say, at the moment when speed ahead ceased. There was a very strong glare of light, some sunshine, and much yellow light reflected from clouds.

Thus we see that in some cases vultures show well-marked colour changes in descent. On other occasions there are no such well-marked colour changes, and in this second class of cases reasons have been adduced for believing that the colours shown when near the ground are due to reflection. It might be suggested that the distinction I have drawn is not due to any objective reality, but is due to some difference in my powers of observing on different occasions. Since writing this chapter I have, however, made further observations that lead me to disbelieve this view, and to expect that it will be possible to formulate the actual atmospheric conditions associated with the two different classes of cases. The main facts of colour appearance are easy to observe in Agra even for the unpractised eye. Once I was walking with a friend in the courtyard of the mosque at Futteypur-Sikri, which is paved with red stone. We saw a scavenger circling at a height of about seven metres over our heads. It showed the usual yellow colour. Seeing it changing its course, I said to my friend that the yellow colour was going to deepen. As I spoke it made a double dip, and the colour flush was as distinctly visible to my friend as to myself. On the other hand, the colour changes consequent on turning down wing-tips in descent, when there is very little time for making the observation, are generally difficult to observe.

In addition to the above exceptions, vultures and scavengers, when circling at low level in not fully soarable air, and especially in the presence of cloud, may occasionally appear nearly or quite white. In such cases it sometimes happens that the colour is only visible

from behind. In all cases the colour is more strongly visible from behind than from in front in circling or flex-gliding vultures. The wings of adjutant birds are dark grey, the body is white. I have made a few observations of colour phenomena in these birds. When taking energy from the air, the body, and especially the undermost portion of the body, appears pale yellow. Occasionally I have noticed a loss of this colour when settling.

It is difficult to see why there should be a relation between consumption of air energy and depth of colour. The colour changes may be of an entirely incidental nature. On the other hand, there may be some kind of a causal connection between the phenomena. So long as we are ignorant of the mechanism by which sun energy is stored in the air, and of the means by which it becomes available for soaring flight, it would be rash to assert definitely that no casual relation exists. All that can be said is, that it is *a priori* highly improbable that colour production is a part of the process of using air energy. But hitherto *a priori* opinions have hindered rather than aided research in the subject of soaring flight. Further facts are needed. I have reasons for thinking that other physical appearances accompany the using of air energy, and wait to be investigated. It is only by patient accumulation of facts that we can hope to solve the secret of the air.

CHAPTER XIX.

THE RELATIVE EFFICIENCY OF DIFFERENT WING FORMS IN RESPECT OF SOARING FLIGHT.

The wings of birds have the appearance of being highly specialised organs, and it is scarcely probable that the differences between one wing and another are of a nature that might be described as due to chance. It is, on the other hand, probable that the different forms of wings are related to the varied habits of their possessors. But what this relation is it is by no means easy to determine, and I can only bring forward a limited number of facts bearing on the point.

Supposing one bird is chasing another, both being in flapping flight, the bird that shows the higher speed may do so, not because its wing form is better adapted for speed, but because its wing is furnished with stronger muscles or because these muscles are actuated by stronger nervous impulses. Difficulties of this nature are to a certain extent removed when we compare the performances of different birds, not in flapping, but in gliding flight.

It is a matter of common observation that a group of birds consisting of vultures and eagles, while circling, should drift two or three miles to leeward of Jharna Nullah. They then flex-glide together back to their starting point. While flex-gliding they appear to keep their relative position. After a flex-glide of two or three miles in an up-wind direction, the eagles may be seen to have maintained their relative position. They show no sign of having been out-distanced by the vultures.

But the vultures have a loading which, in some cases, may be nearly double of that of the eagle. That is to say, the wing of the vulture appears to take more energy from the air than the wing of the eagle, supposing that the resistance of the bodies of the birds to passage through the air is equal. It is impossible to imagine that the vulture is aided in its flight by having a better body form than the other bird. Its large head and thick clumsy neck are in strong contrast to the graceful outline of the eagle.

But this line of argument is the reverse of conclusive. It is possible that the eagle has in reality a better wing form (in respect of speed), and that it habitually checks its speed (by previously described adjustments) in order to match that of the vultures in whose company it is flying.

More information as to the relative efficiency of different kinds of wings, in respect of gliding, may be obtained by a study of the extraordinary evolutions of birds when playing together or teasing one another in the air. Some of the movements involved are so transient and rapid that it was only after prolonged practice that I was able to form an idea of their nature.

In the case of eagles and cheels playing together in soarable air, the cheel, though the smaller bird, is always the aggressor. A cheel swoops down towards the eagle. The latter defends itself by threatening the cheel with its beak and claws. If the cheel is very persistent, the eagle may increase its speed by flapping. I have seen three cheels teasing an Indian Tawny Eagle (*Aquila virdiana*). They swooped down towards it one after the other. Each, after swooping to a lower level than the eagle, turned rapidly and made a few flaps

to regain a position above that of their victim. Otherwise the flight of the cheels was almost entirely by gliding. Despite their up and down course, they were able to keep up with the eagle, though the latter bird was in continued flapping flight. This was in soarable air at a height of about 100 metres.

In the case of cheels playing together it frequently happens that two birds catch hold of each other by the claws. One bird swoops down towards the other. A sudden irregular movement ensues, too rapid for even the practised eye to follow. One cheel is then seen suspended by its claws from the claws of the other. This suspended cheel is upside down. The two cheels are falling through the air with loud screaming and twittering. While falling they are rotating round a vertical axis. After thus falling for a few seconds they come apart and glide off in different directions. During this play it appears to be, so to speak, a point of etiquette that the wings of the two birds should not come into contact. A clue as to the nature of the movement by which the two cheels catch hold of each other is afforded by the following observations:

30th November, 1912. At 2.0 p.m.—A cheel seen swooping downwards towards an eagle (*Aquila hastata*). The latter, in order to threaten the cheel, rotated through about 100° round its longitudinal axis, meanwhile extending its claws in the direction of the cheel. The eagle, without pause or jolt, immediately rotated back to its previous position. The eagle was gliding horizontally, and the rotation caused no visible loss of height or interruption of the glide. The bird was travelling in my direction, so that I was seeing it in end-on view. Had the bird rotated through only 90° , then one wing-tip would have pointed to the sky, and the other to the earth. It was clearly seen to rotate beyond this position, so that anyone standing directly underneath the bird would have had a glimpse of the upper surface of the wings.

29th January, 1913. At 1.4.—A bird of unknown species was seen circling. It was attacked by a scavenger. It repeatedly rotated through about 100° round its longitudinal axis in order to threaten the scavenger with its claws. At the time it was gliding with slight loss of height.

I saw what I believe was this same bird in flight on another occasion, and shot it on the 11th February, 1913. It was the Honey Buzzard (*Pernis cristatus*). It had a span of 52in., and a loading of .71 lb. per square foot of wing area. The loading of a scavenger vulture was found by me to be .87 lb. per square foot.

It is a matter of fairly frequent observation that, in soarable air a cheel when chasing a Tawny Eagle can flex-glide at a higher speed. But it is not always possible to be certain that both birds are gliding horizontally. That is to say, the possibility cannot always be excluded that the cheel is gliding with loss of height, and thus increasing its speed with the help of gravity. This was certainly not the case in the following instance, which was observed from the roof of my house, and in which the birds were not greatly above my level:

11th November, 1912. At 12.34.—Two cheels seen chasing an eagle (*Aquila vindiana*). Presently one cheel and the eagle caught hold of one another by the claws. In this position they rotated round one another with wings spread out. The rotation was round a vertical axis that passed between the two birds—that is to say, the birds moved round one another as if waltzing. One was not suspended below the other, as more usually happens in such cases. Then the two birds came apart, and the cheel glided a short distance in a direction away from the eagle, and with loss of height. Then the cheel turned, and again began chasing the eagle. While doing so it lift-glided with a clearly shown gain of height. In this way it rapidly overtook the eagle, although the latter bird was gliding horizontally. The eagle made two or three flaps as the cheel approached. The cheel, having overtaken the eagle, passed it, and flex-glided away with a further increase of speed.

On a later occasion I shot a Tawny Eagle which I have grounds for believing was the same specimen as had been seen in the above observation. Its span was found to be 66in., and the loading was .68 lb. per square foot.

Since making the above observations, I have frequently been able to see that when birds are thus

teasing one another in the air, the bird that is being chased replies by a sudden to and fro longitudinal axis rotation with display of its claws. The rotation is usually only of from 20° to 30° . It is always so rapid that it can only be recognised with practice.

In the above-described observations three different species of birds, having wing sections which are about to be described as "aquiline" or "strigine," showed less gliding speed in soarable air than two species of birds whose wing sections are about to be described as "vulturine." Such differences of speed are only observed in soarable air. For cheels to tease an eagle may be described as a matter of common observation. But this only happens in fully soarable air and at some height above the ground.

But the evidence bearing on the efficiency of the different wing forms is not exhausted.

Blanford, in "Fauna of British India," Vol. III., Birds, 1895, page 339, says of *Aquila vindiana*: ". . . but it also subsists to a great extent by robbing smaller birds, such as kites and falcons, of their captures; and Elliot long since called attention to its troublesome habit of pursuing tame falcons owing to its mistaking the jesses for prey." ("Jesses" are small pieces of leather tied to the feet of the falcons.)

Jerdon, in "Birds of India," 1877 edition, page 61, says of the same bird: "It, however, subsists habitually by robbing kites, falcons, and other birds of prey of their earnings; and may often be seen pursuing a kite with great impetuosity, and always succeeds in getting the desired morsel."

Thus we see that in fully soarable air, the cheel can glide faster than the eagle, and this even when

the cheel has to glide uphill in chase of an eagle gliding on the level. But in the experience of the observers now quoted, the eagle has the advantage in speed over the cheel. But in these latter cases there can be no doubt that both birds were in flapping flight.

Thus the facts of the case indicate that the cheel can glide faster than the eagle, but that the eagle can flap faster than the cheel. The faster gliding of the cheel has only been observed in fully soarable air. The question remains to be settled by further observation whether the advantage in speed of the eagle in flapping exists in fully soarable air or whether it only exists at low levels or at times of the day when the air is unsoarable or not fully soarable. It is to be hoped that this point will attract the attention of other observers.

It may be remarked that it is difficult to understand how anyone could see cheels and eagles playing together in the air and still believe that soaring flight is due to birds having to hunt for and take advantage of chance ascending currents. The complicated movements of the cheel as it glides in any direction to meet or avoid the other birds are only explicable on the view that every minute portion of soarable air is as ready as every other portion to yield energy for its flight.

We may now pass on to consider what may be learnt from a study of the wing sections of different kinds of birds.

There is a singular similarity in outline, in width, and in certain cases in length, between the wings of the following birds :

The Blue Heron (*Ardea cinerea*).

The Long-legged Eagle (*Aquila hastata*).

The Dusky Horned Owl (*Urrua coromanda*).

The Honey Buzzard (*Pernis cristatus*).

The Black Vulture (*Otogyps calvus*).

These birds have widely different habits. If the wings are adapted to the habits of the owners the adaptation does not seem to have affected the characters mentioned.

There is less air space between the wing-tip feathers of the owl and the heron, when the wing is extended, than there is between the wing-tip feathers of the other birds mentioned. Other small differences in outline may no doubt be found, but it is difficult to believe that such trivial differences have any important relation to the habits of their owners.

But the wings of the birds mentioned above differ widely in the outlines of their cross sections. If soaring flight is due to the bird having a good gliding angle, and therefore being able to take advantage of some unknown upward trend in the wind, then one would expect that the bird whose wing section permits of the smallest gliding angle would be the most expert at soaring flight. Current explanations of soaring flight usually commence with the avowed assumption that soaring birds have a good gliding angle. Such explanations have so often been contradicted by the facts of the case in other respects, that it will be of interest to see whether they are also contradicted by the facts of the case as to wing cross sections.

To discover the gliding angle of a bird by direct observation is difficult for two reasons: Firstly, in any given case, one cannot be sure that the bird is doing its best. Secondly, if a bird is gliding up-wind with gain of height, then this gain of height will be increased (relatively to the earth) by the fact of the presence of wind. Alternatively, if a bird is gliding up-wind with loss of height, then the action of the wind is to increase

the apparent loss relatively to the earth. The converse appearances will be produced if the bird is gliding to leeward. These deductions apply to a case in which the wind is blowing horizontally and is uniform. If, as is likely to occur in practice, the wind is not uniform, then it becomes still more difficult to form an opinion as to the gliding angle from the apparent loss or gain of height of a bird gliding with or against the wind.

As direct observations of gliding angles are thus likely to be vitiated by large sources of error, it becomes the more important to study the cross sections of the wings of different birds. If two wings are similar in size and outline and differ widely in their cross sections it is possible, in the present state of aeronautical knowledge, to make some guess as to which bird has the best gliding angle.

Current drawings of wing sections are defective in that they represent the wing shape when the bird is in still air. They make no allowance for the fact that certain of the covert feathers stand out from the wing in the absence of air pressure, but are pressed tightly against the body of the wing while the bird is in gliding flight. In some cases the covert feathers on the under side of the wing near its anterior margin are thus pressed upwards, leaving a cavity, which may be called the "patagial depression," and which, under favourable circumstances, may be observed during gliding flight. In the case of the owl the patagial depression is practically absent but the covert feathers on the upper side of the wing stand out, so that in flight the wing is probably of thinner section than it is in still air. In the case of the Blue Heron, the feathers both on the upper and under sides of the wing thus stand out, and

are readily pressed back to the body of the wing by gentle pressure, but in doing so seem to leave no trace of a patagial depression.

In order to obtain a section of the wing, I adopted the following procedure: An ordinary laboratory retort stand having two clamps was employed to hold the wing. Two or three of the primary quills were clasped between two small pieces of cardboard, which again were clasped by the upper of the two clamps. As a precaution against slipping, the opposed surfaces of the pieces of cardboard had been covered with a layer of plasticine. The upper clamp was raised until the body of the bird was partly lifted from the table. The second clamp was then adjusted near the base of the wing. The wing as thus held has a greater degree of camber than is the case in flight. The secondary quills were therefore pressed back to what appeared to me to be a suitable amount. That is to say, the amount of camber shown in the accompanying figures of wing sections is a matter of guesswork based on my recollection of the appearance of birds in flight. As the camber of the wing can be varied at the will of the bird, it is probable that each wing section shown represents a shape that occurs in nature, but it is impossible to be sure to which kind of flight a particular wing section is appropriate.

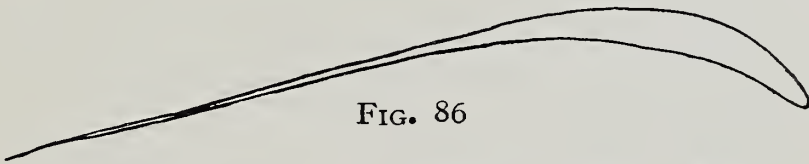
In order to imitate wind pressure, I made the covert feathers adhere to the body of the wing by the simple expedient of painting them with melted paraffin.

Having thus arranged the wing with its long axis vertical, I took a plaster cast of its central portion. To do this I first fixed two wooden platforms horizontally one on each side of the wing.

The platforms were on the same level. They were brought as near to the wing and each other as possible, and clamped in position. The space between each wooden platform and the wing was filled up with the help of a number of narrow strips of tin, which were laid side by side on the wooden surface. On the flat surface thus formed was spread a layer of plasticine. This was made level, and on each side pressed up into close contact with the wing. A wall of plasticine was built up round the edge of the surface thus obtained. In this way a mould was formed, into which plaster of Paris could be poured. This plaster was poured in in two portions. The first portion was tinted with a colouring matter. Leaks were stopped with the help of dry plaster of Paris. After this first layer had set, the surface moisture was removed with blotting-paper. French chalk was then peppered over the surface of the plaster. The second quantity of plaster (not tinted) was then poured in. Coverslips made greasy by rubbing with a piece of plasticine were stuck into the plaster at each end, before it had set, so that the cast when made easily separated into two pieces. Owing to the use of the French chalk the two layers of the plaster easily separated after setting. The tinted layer was discarded. Its use was partly to stop leaks and partly to obtain a horizontal surface for the underside of the actual cast. The platform was arranged at such a height that the resulting section was taken generally midway between the carpal and elbow joints of the wing.

To draw the section the two pieces of the cast were laid together in position on a table. A tracing was then made with tracing paper. For tracing paper I generally used a sheet of foolscap wetted with petrol.

In spite of the above-mentioned possible error with regard to camber, the wing sections thus obtained are probably more accurate than others hitherto published. It may be noted that errors in execution are likely to be proportionately less in the case of large wings than in the case of wings of small birds. The accompanying figures of wing sections are all made from birds of large size.



Wing section of Blue Heron (*Ardea cinerea*).

We may now proceed to consider the results obtained. Fig. 86 shows a section of the wing of the Blue Heron (*Ardea cinerea*). The span of this bird was 70 in. Its loading was found to be .79 lb. per square foot. The thinness of the section suggests that the bird has a small gliding angle. My observations on this bird in flight are not numerous but so far as they go they support this view. In an earlier chapter I deduced from the flapping flight of this bird that its angle of incidence is small. In gliding flight it appears to me to glide with but slight loss of height and with a small angle of incidence. So far I have seen no trace of an increase of the angle of incidence during the glide. Neither have I ever seen it glide with its wings in a dihedrally-up position.¹

¹ During a trip in the Sunderbuns (Gangetic Delta), I observed many specimens of the Large White Egret (*Herodias alba*). This is a bird allied to the herons, and, according to Jerdon, has a span of 54 in. On one occasion I saw one gliding while being lifted by an air current reflected upwards from some high trees. But as a rule these birds appear to glide only before settling. During the glides, which may be somewhat prolonged, the wings are arched, and the loss of height is gradual. In other words, this bird shows a good gliding angle. During the glide there is no sign of any increase of the angle of incidence due to change of the dihedral angle of the wings. Just before perching there is an increase of the angle of incidence due to advancing of the wings. This is ordinary "stop descent," with its usual rapid loss of speed. Rarely this stop descent produces a slight and temporary gain of height. That is to say in numerous observations it was found that the gliding of the large egret resembles that of herons, and differs from that of birds with a vulturine wing section. I have made similar observations in the case of the Pond Heron (*Ardeola grayi*).

Thus the study of the wing section suggests that the Blue Heron is a bird with a good gliding angle. Nothing in my observations of the bird in flight goes against this view.

If the Blue Heron has a good gliding angle, and if soaring flight is due to the bird being lifted by some unknown upward trend in the wind, then the Blue Heron ought to be able to soar. The power of soaring flight has been ascribed to the Heron by one or two observers. It is a matter in which further observation is required.

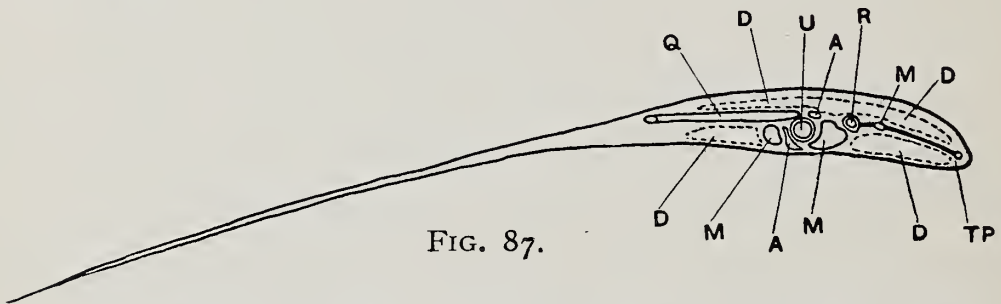


FIG. 87.

Wing section of Dusky Horned Owl (*Urrua coromanda*), taken midway between carpal and elbow joints.

- | | | | |
|-------|---------------------------------|-------|---------------------------|
| D, D. | Down shown with dotted outline. | T, P. | Tensor patagii tendon. |
| M. | Muscle. | Q. | Shaft of secondary quill. |
| A. | Air sac. | R. | Radius. |
| | | U. | Ulna. |

Fig. 87 is a section of the wing of the Dusky Horned Owl (*Urrua coromanda*). The span of the specimen from which this section was made was 55in. Its loading was .88 lb. per square foot. I obtained a very similar wing section from another owl, namely, the Spotted Owlet (*Athene brama*), having a loading of .47 lb. per square foot.

The slenderness of the wing section suggests that the owl has a good gliding angle. On one or perhaps two occasions I have seen a large owl gliding in calm air with what appeared to me to be a surprisingly small loss of height. Probably this impression was produced on me because, at the time, I was studying the flight

of Flying-foxes (*Pteropus*). These bats glide with a well-marked loss of height, and the bones stand out as ridges on the undersides of their wings.

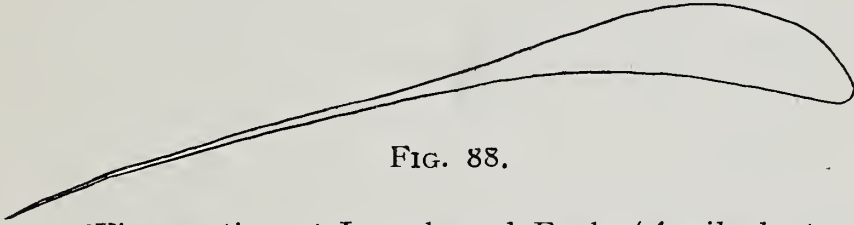


FIG. 88.

Wing section of Long-legged Eagle (*Aquila hastata*).

I propose the term "strigine" for a wing section similar to that of the owl. The wing section of the Blue Heron may also, at present, be included under this term.

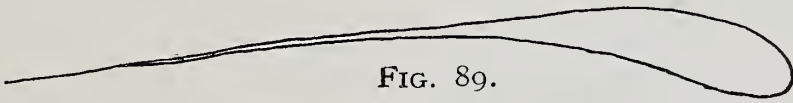


FIG. 89.

Wing section of Honey Buzzard (*Pernis cristatus*).

Fig. 88 represents a section of the wing of the Long-legged Eagle (*Aquila hastata*). Fig. 89 shows a wing section of the Honey Buzzard (*Pernis cristatus*). These wing sections may be described as "aquiline." The wing section of the Tawny Eagle (*Aquila vindaiana*), shown in fig. 90, obviously approximates to the strigine

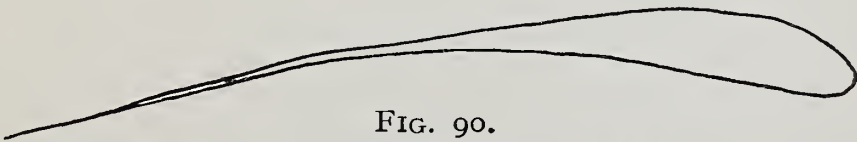


FIG. 90.

Wing section of Indian Tawny Eagle (*Aquila vindaiana*).

type. The wings of this eagle resemble those of owls also in that the under surface of the quill feathers is somewhat polished. Further the shafts of the primary quills do not stand out so strongly on the underside of the feathers as do those of vultures and other species of eagle that I have examined.

These wing sections suggest that their possessors may have a somewhat good gliding angle. Without wishing to lay too much stress on observations on this point, I may state that occasionally I have seen birds with aquiline wing sections gliding in calm air with a

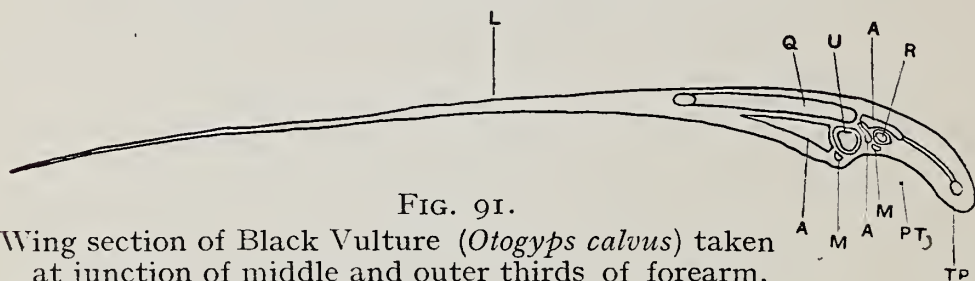


FIG. 91.

Wing section of Black Vulture (*Otogyps calvus*) taken at junction of middle and outer thirds of forearm.

- | | |
|--|---------------------------|
| Q. Shaft of secondary quill. | A. Air sac. |
| L. Posterior limit of covert feathers. | M. Muscle. |
| U. Ulna. | T.P. Tensor patagii. |
| R. Radius. | P.T. Patagial depression. |

gliding angle that appeared to me to be good, as compared with that of vultures when, as rarely happens, these birds glide with loss of height in unsoarable air. I have never yet seen in eagles an increase of the angle of incidence during the glide, as usually happens in unsoarable air in the case of the heavier vultures.

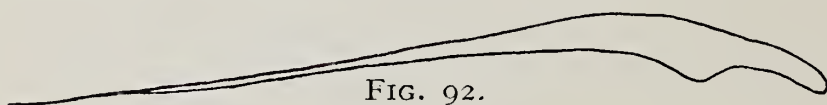


FIG. 92.

Wing section of Cheel (*Milvus govinda*).

A wing section of the Black Vulture is shown in fig. 91. This may be compared with another wing section of the same bird, shown in fig. 29. A wing section of the cheel is shown in fig. 92. All of these wing sections show a well-marked "patagial depression." I have obtained similar wing sections in the case of the Common Vulture (*Pseudogyps bengalensis*) and the Scavenger (*Neophron gingianus*). These wing sections may be described as "vulturine."

In order to be sure that the presence of the patagial depression was not due to any post mortem shrinking of the tissues or deflation of air sacs, it occurred to me that it would be advisable for me to examine birds in the living condition. I am indebted to the kindness of Mr. B. Basu, the Superintendent of the Calcutta Zoological Gardens, for his kindness in giving me opportunities for so doing. We found that in the Sarus (*Grus antigone*) and the Adjutant (*Leptoptilus dubius*) the patagial depression was even larger than in vultures. In the latter bird the depression was nearly destitute of feathers. In the Black Necked Stork (*Xenorhyncus asiaticus*) the patagial depression was a little smaller than in the adjutant, but limited posteriorly by a very sharp ridge formed by the radius. In the Common Stork (*Ciconia alba*) the patagial depression appeared to be large and more marked distally than nearer the base of the wing. It was also present in the Cape Crowned Crane and in the Flamingo. In the latter bird the anterior margin of the patagium appeared to be somewhat thickened, and I noticed that the metacarpal quill mass was cambered. In two species of heron I found that a slight patagial depression could be formed by sufficient pressure on the surface of the feathers, but the tissues of the wing of this bird are so soft and pliable that pressure on one side of the patagium is likely to produce bulging on the other, and the wing section of the heron already given is likely to be more accurate than such observations from the living bird.¹

Thus the vulturine wing section is characterised by the presence of the patagial depression. This depression

¹ Cranes, storks, and herons should be handled with care, as they have the habit of making a sudden and well-aimed peck at the eye of anyone with whom they are angry. I have heard of a case of a boy losing the sight of one eye, in this way, from the attack of an ordinary pond heron whose nest he had disturbed.

is limited posteriorly by the bones and tendons of the wing. That is to say, in the more efficient soaring birds, whether of heavy loading (such as vultures and adjutants) or of light loading (such as cheels and scavengers), the underside of the wing presents a prominent ridge transverse to the line of flight. That the presence of this ridge, especially in birds of heavy loading, should result in a bad gliding angle, is *a priori* probable. The facts of observation tend to support this supposition. In the case of the Common Vulture, the Black Vulture, the Scavenger, and the Adjutant, I have been able to see that during the glide there is a gradual increase in the angle of incidence. This is the case when these birds are gliding approximately horizontally in unsoarable air. In the case of the Adjutant and the Common Vulture I have also been able to see the gradual increase in the dihedrally-up angle of the wings, by which the increase in the angle of incidence is brought about. I suggest that these birds have such a bad gliding angle that they are obliged to adopt this manœuvre; in other words that if they attempted to glide, as does the Blue Heron, without this manœuvre, there would be an excessive loss of height.

There is a further difference between the wing of the owl and the wing of the vulture.¹ I found that in the Spotted Owlet (*Athene brama*), if the distance from the body to the carpal joint is taken at 1, then the distance from the carpal joint to the tip of the wing is $2\frac{1}{2}$. In the vulture, on the other hand, the corresponding ratio is $1 : 1\frac{1}{6}$. That is to say, in the case of the vulture, the carpal joint stands not far from the

¹ Mr. Howard Short informs me that the length of the primaries, as compared with the length of the arm bones of the wing, varies in different classes of birds, and has no apparent relation to the absence or presence of the power of soaring flight, though relatively long primaries are very frequently met with in the smaller birds.

centre of the wing. Nearly the whole of the inner half of the wing is occupied by bones standing out strongly on the under surface, which form a ridge transverse to the line of flight. In the owl this part of the wing having bony ridges is reduced and the greater part of the length of the wing is occupied by quill feathers.

In the case of vultures the leading edge of most of the outer half of the wing is occupied by the primary quills which also present ridges transverse to the line of flight. These ridges are formed by the shafts of the quill feathers, which stand out prominently on the under surface, but are flush with the upper surface of the web of the feathers.

The silence of the flight of owls has been noted by many observers. This character is probably due not only to the delicacy of their wing sections, but also to the fact that, especially in the larger owls, the under surface of the feathers is highly polished. The shafts of the primary quills are nearly or quite flush with the surface of the web and the web on the leading margin of these feathers is soft, pliable, and serrated in outline.

The silence of the flight of owls may be contrasted with the loud whirring sound made by the wings of vultures when they are gliding in soarable air. The sound made by vultures in circling has been mentioned elsewhere. When a vulture is diving by shoulder descent it makes a loud crackling roaring sound, such as would be produced by a large rocket. In the case of two Black Vultures playing together in the air, on one occasion I noticed that, when they dived in this way, the roaring sound was plainly audible at a distance of 200 to 300 metres, despite the presence of wind at the

time. On the other hand when vultures are in carpal descent and, it may be remarked, no longer taking energy from the air, no roaring sound is produced.

Whatever the whirring sound made by vultures in soarable air may be due to I am confident that it is not caused by, or associated with any movements of individual feathers. Movements of the covert or other feathers may occur, under certain conditions, in carpal descent, and also in stop descent, but in these forms of flight no noticeable sound occurs. When vultures are circling and making a whirring sound I have been able to observe that every covert feather was tightly pressed against the body of the wing.

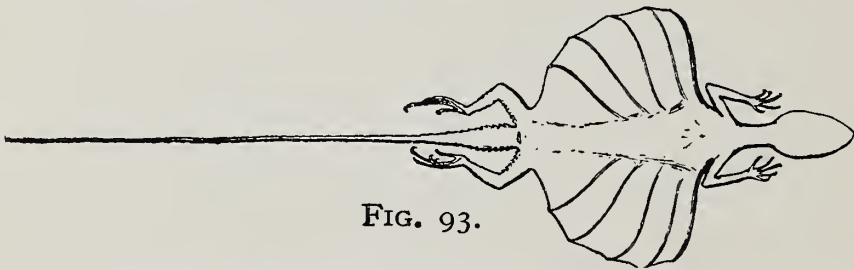


FIG. 93.

Outline of Flying Lizard (*Draco maculatus*), drawn by Mr. G. Howard Short from a sketch by the author.

I have elsewhere quoted an observation to the effect that flying-fishes make a loud humming noise when in flight. In these animals the fin rays stand out as sharp ridges on the undersides of the wing. It is interesting to contrast this feature of the wings of flying-fishes with the smoothness of the wings of flying-lizards belonging to the genus *Draco*. Owing to the kindness of Mr. S. W. Kemp, of the Indian Museum, Calcutta, I was able to examine specimens of *Draco volans* and *Draco maculatus*.

Fourteen species of these lizards are known. A few are found in Southern India. Most of them are confined to the Malay Peninsula and Archipelago. They

are generally about 6in. or 7in. in length. The wings are lateral expansions of the body supported by five or six elongated ribs (fig. 93). The anterior margin of the wing is formed by two closely apposed ribs and a small amount of muscular tissue. That is to say, the anterior margin is very slightly thickened.¹ The under surface of the wings is otherwise almost completely smooth. When at rest the wings are furled against the sides of the body. The muscles for advancing the wings appear to be of a somewhat complicated nature.

I have to thank Dr. H. N. Ridley, of Singapore, for giving me some information about their flight. They often make glides of 40 to 50 metres in length. They do so with a loss of height of about 1 in 4. Dr. Ridley

¹ It appears to be a general rule that in all classes of flying animals the greatest strength of the wing should be at or near the anterior margin. Apparent exceptions to this rule are presented by the flying frogs and the flying geckos of the Malay Peninsula. But Annandale and Robinson have shown that there is no sufficient reason for believing that these animals either fly or glide. Current drawings of the flying frog, showing monstrous feet with the webs between the toes acting as parachutes, are exaggerated. The feet are really much smaller. Their web probably aids the suckers on the toes in holding on to the tree or aids in concealment.* In the case of the flying gecko, the so-called parachute expansions of the body appear to remain tucked up against the side during a jump, and have no such stiffness as would be necessary for supporting the weight of the body in gliding. (See "Fasciculi Mayalenses," pp. 138 and 151, published by the Liverpool University Press in 1903.) On the other hand, among the minutest known flying insects, cases occur in which there is no strengthening of the anterior margin of the wings. In the Mymaridæ among the Hymenoptera and the Trichopterygia among the Coleoptera, the wings each consist of a central rod fringed all round by a row of stiff bristles. (See "Description of a Minute Hymenopterous Insect from Calcutta," by N. Annandale, in "Records of the Indian Museum," Vol. III., 1909, page 299, and "Description of Some Minute Hymenopterous Insects," by Westwood, in "Transactions of the Linnean Society, Second Series, Zoology," Vol. I., 1879, page 583.)

* Siedlecki ("Zur Kenntniss des Javanischen Flugfrosches," published in Biologisches Centralblatt, Vol. XXIX., 1909, pages 704 and 715) has published a description of a flying-frog that has very large webs between the toes of the hind feet. He says that when starting from a flat surface this frog can make a spring of $1\frac{1}{2}$ to 2 metres. It covers this distance in from a quarter to one-third of a second. He says that he has seen, during a jump or glide, a few strong beats of one hind leg made in order to produce a change of direction of the flight. This statement is rather difficult to believe, as also is his statement that the animal dilates its lungs before a flight in order to decrease its specific gravity. There is no more reason for believing that a cold-blooded animal can change its specific gravity by swallowing air than for believing that a fish could change its specific gravity by swallowing water. The term "specific gravity" is a misnomer when used in this connection. The term "buoyancy" would be better used in connection with Siedlecki's mistaken idea. Buoyancy is not a factor of great importance in connection with the power of flight. The Snake Bird, for instance, when in the water habitually swims with its body completely immersed. Only the head and neck are kept above the surface. This bird is a rapid and powerful flier. Its wings, judging from an examination made without taking a section, appeared to me to be very slightly cambered and of very thin ("strigine") cross section. The *Abductor pinnæ* muscle appeared to be reduced and the power of wing-tip rotation was greater than in herons and less than in vultures. In the case of birds in the hot weather in the plains of India, when the temperature of the outside air may be equal to or greater than the body temperature of the bird, there can obviously be no increase in buoyancy from dilation of the air sacs. Locusts and other fast-flying insects possess air sacs formed by dilations on the tracheæ. The May Flies are stated to keep their stomachs dilated with air during flight. Baer has adduced grounds for believing that the air sacs of birds in some way aid respiration ("Zur Physiologischen Bedeutung der Luftsäcke bei Vögeln," Biologisches Centralblatt, Vol. XVII., 1897, page 282).

has seen one steering to avoid a tree. In so doing it became canted. It may be noted that their wing structure is such that if the muscles for advancing one wing are slightly relaxed, this wing would be retired, and its camber would be increased. This adjustment would be likely to produce both the steering and the canting effect.¹

According to Dr. Ridley, these lizards feed on ants which they find on the tree trunks. He does not think they catch insects while in flight, as has been stated by Cantor.² They rarely fly in a wind. In forests they generally glide in heavy shade. As they reach the tree trunk on which they are about to alight, they rotate slightly round their transverse axis, thus gliding upwards for a short distance to check speed. Otherwise their flight is always with well-marked loss of height.

Had ridges transverse to the line of flight been of advantage for gliding in unsoarable air, one would expect them to have been evolved from the wing ribs of these lizards. As a matter of fact, the ribs scarcely stand out at all from the lower surface of the wing.³

¹ Reasons have been given in earlier chapters for believing that birds and bats, when gliding, steer by giving the inside wing a degree of camber unsuited to its angle of incidence. It has also been shown to be possible that flying-fishes and flying lizards employ a similar method of steering. In a paper entitled "The Development of Animal Flight" (*Aeronautical Journal*, Vol. XVI., January, 1912, page 24), I suggested that the "pteroid" bone of pterodactyles may be the first digit modified to support a part of the wing membrane used for varying camber, and that hence these animals may have steered by the same method. That is to say, no flying animals are known that steer from side to side by means of a vertical rudder analogous to the vertical rudder of aeroplanes. A possible exception to this statement is presented by the vertical fin at the end of the tail of the pterodactyl *Rhamphorhynchus*. But, in view of the small size of this organ, it seems more probable that its use was to steer while the animal was on the water. Possibly *Rhamphorhynchus* was in the habit of flapping along the surface of the water with the tail immersed. Existing evidence goes to show that pterodactyles were of fish-eating or insect-eating habits. If the structure of the wing of *Archæopteryx* did not permit of varying camber, it appears likely that it steered from side to side by varying the relative strength of the beats of the two wings—that is to say, that it could only steer while in flapping flight. In flapping flight, wing beats of different strengths of the two wings play a part in steering from side to side, as has been shown, with the help of a series of remarkable photographs, by F. W. Headley ("The Flight of Birds," London, 1912).

² Quoted in "Ray Society, Reptiles of British India," Gunther. (Harwicke, London, 1864.)

³ The statement made by Deninger that flying lizards are inflated like a balloon, the inflation including both body and wings during flight, is highly improbable on anatomical grounds, and requires investigation, especially with the help of dissection of fresh specimens. (See "Naturwissenschaftliche Wochenschrift," New Series, January, 1910, Vol. IX., No. 2, page 20; "Ueber das Fliegen der Fliegenden Eidechsen," by Dr. K. Deninger.) An inflated lizard could not cant and steer, as described by Dr. Ridley. Many lizards make a hissing sound when caught. This might be the origin of the supposed deflation noted by Deninger when he caught one of these animals.

The flying lizard has a smooth under surface to its wing and always glides with a downward slant. The flying-fish has ridges on the under surface of its wing, and in soarable air can glide for 100 metres or more without loss of height or speed.

There can be little doubt that the presence of transverse ridges on the undersides of the wings of soaring animals must result in the air under the wing being in a state of intense disturbance. On the other hand, it is probable that the air flows over the upper surface of the wing in an even stream. The sound produced by vultures and flying-fishes, when gliding in soarable air, may be regarded as a proof that air disturbance occurs. If air is disturbed work must be done and one would expect this work to be done at the expense of speed. Some of the facts brought forward in this chapter indicate that ridges transverse to the line of flight are detrimental for gliding flight in unsoarable air. But the extraordinary thing is that no reason has been found for believing that they are detrimental in soarable air. On the other hand, so far as the facts have been elucidated, these ridges appear to be more developed in soaring animals of higher efficiency and heavier loading. All that can be definitely affirmed in the present state of our knowledge is that the structure of the wings of soaring birds is the reverse of what one would expect on the theory that their flight is due to chance ascending currents or to an upward trend in the wind. But we may obviously hope and expect that a further study of wing structure will throw light on the unknown process by which soaring birds, and also flying-fishes, get energy from the air. More than one line of research is indicated by the facts now known about

ridges transverse to the line of flight. The presence of such ridges in the wing of an insect will be described in the following chapter.

In Chapter XVII. it has been shown that the cause of transverse axis instability has some close connection with the cause of soarability. In view of the facts now brought forward it is of interest to notice that the transverse axis instability evidenced by tail-jolting occurs frequently only in birds of vulturine wing section. Further observations on this point are, however, required.

ADDENDUM TO CHAPTER XIX.

The following remarks by the Duke of Argyll indicate that the heron has the power of soaring flight : "I have never seen any notice of the peculiar habits of the heron at the pairing season. All birds, as you know, have some peculiarities of manner at that season. Storks and cranes seem (at the Zoological Gardens) to dance and caper on their long legs. The herons fly round in circles with a soaring flight, frequently stretching out their necks at nearly full length, which they never do in ordinary flight. The balance of the bird seems to require the long neck to be folded. But at this season, when love making, they extend the neck and float about in the air in wheeling circles round and above the trees where they are to nest. Yesterday morning, which was fine and sunny, there were nine herons floating and soaring in wide circles above the castle here, and in front of the steep wooded hill on which they build." (The Duke of Argyll, "Autobiography and Memoirs," edited by the Dowager Duchess of Argyll, Vol. II., page 504. John Murray, 1906.)

CHAPTER XX.

ON THE FLIGHT OF DRAGON-FLIES.

We have seen that vultures and cheels have an instinct that tends to make them indulge in soaring flight whenever atmospheric conditions are suitable. At Jharna Nullah a number of vultures may be seen circling at any time when the air is soarable, though every yard they glide brings them further away from their food. It would seem as if nature has given these birds an instinct that makes them enjoy soaring flight. It is scarcely likely that nature would have given them this instinct had soaring flight depended on their own muscular exertions. As we have found the necessary energy is obtained in some unknown way from the air.

Dragon-flies may similarly be seen flying together for hours at a time, apparently combining business and pleasure in their flight, after the manner of the soaring birds. Mr. B. G. Cooper first made me acquainted with the fact that dragon-flies can glide for long distances.¹ It seemed to me that the matter would be worth investigation.

The commonest species of dragon-fly present in Agra has a span of $3\frac{3}{8}$ in. Its eyes are brown. The thorax and abdomen are of a dull yellow colour with black markings. There is a small area of transparent yellow colour near the base of the hind wings.² The weight of one of these insects was found to be .261

¹ See the *Aeronautical Journal*, January, 1912, Vol. XVI., page 38.

² I am indebted to Mr. Grove, of the Agricultural Research Institute, Pusa, for identifying this species as *Pantala flavescens*. A similar species often seen in company with the first-named is *Tramea burmeisteri*. Dr. Harmer and Mr. G. M. Waldo, of the South Kensington Natural History Museum, have also helped me in identifying different species of dragon-flies.

gram, and the loading was .032 lb. per square foot. This result may be compared with the following figures found for the loading of butter-flies: *Argynnis childreni* .024, and *Papilio ravana* .028 lb. per square foot. That is to say, estimated by the loading, the wings of these insects are many times less efficient than are the wings of birds.

Fig. 94 shows an end-on view of this dragon-fly when gliding. The wings are held dihedrally-up. The front wings are more elevated than the hind wings. In rare cases the two front wings are seen to be elevated

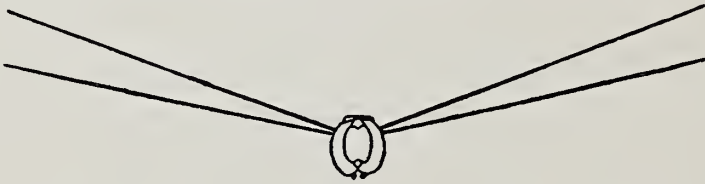


FIG. 94.

End-on view of Dragon-fly (*Pantala*) gliding, showing the dihedrally-up angle of the two pairs of wings. The front wings are longer and more raised than the hind wings.

to different degrees. I have watched this while the insect was gliding in a straight line for several metres. The easiest way of appreciating the fact that the front wings are higher is by seeing the insect in end-on view. The fore wings are a little longer than the hind wings, and it can easily be seen that the longer wings are highest in position.

Side views of the gliding dragon-fly are shown in fig. 95. The legs are doubled on themselves and extend backwards under the abdomen. For the sake of clearness, only one leg is shown in the diagram. Sometimes the legs are held in the position indicated in the drawing. At other times they are placed in contact with the abdomen. I have frequently seen a change from one position to the other during flight in a way that

suggests that the movement is one that accompanies some flight adjustment. But what this adjustment is I have not yet been able to discover.¹ Occasionally I have seen the legs temporarily unfolded and advanced during gliding flight.

It is often difficult to see whether the insect is flapping or gliding. To the untrained observer the space between the front and the hind wings, when seen in end-on view, may produce a blurred effect, suggesting that the wings are in rapid vibration. A little practice will dispose of this source of error.

Another possible source of error is that, under certain conditions, the gliding dragon-fly shows a remarkable amount of lateral instability. The wing-tips of one pair of wings go down, and the wing-tips of the other pair of wings simultaneously go up, to an extent of nearly $\frac{1}{2}$ in. This lateral oscillation goes on at a rate just too rapid to count, and may simulate a rapid fluttering movement of the wings. But instability of this nature only occurs in disturbed weather and usually only late in the afternoon when soarability is decreasing. Thus the movements of a dragon-fly may reveal a lack of homogeneity of the air too fine grained for it to be shown by the movement of a soaring bird.

The gliding flight of dragon-flies, as a rule, is frequently interrupted by a flap or perhaps a short period of flapping. In the absence of hurried flight the period of flapping usually lasts for some small fraction perhaps the tenth of a second. A period of flapping often coincides with a change of course.

¹ A muscle connecting the wing and the leg of dragon-flies (the "pteropodial muscle") is mentioned in "Gli Insetti," by Antonio Berlese, Vol. I., Milan, 1909, pages 392 and 436. Observations made at a later date in Calcutta have shown that the legs hang down only when the abdomen is also hanging down, and that this disposition only occurs in air of a high degree of soarability.

The first impression is that at the moment of flapping there is a sudden change in direction and the insect darts away at a speed too great for the eye to follow. But after practice I have been able to see that the dragon-fly when turning first becomes canted and turns, and then having turned the short period of flapping ensues. That is to say, the flapping compensates for the loss of speed consequent on a steering action. Occasionally the insect turns with canting, without the subsequent help of flapping. This only occurs in highly soarable air.¹

As a rule, in flapping of this nature, only the hind wings are flapped, while the front wings remain supporting the animal in its gliding flight. I have seen the front wings at rest while the hind wings were flapping both when the insect was overhead, when seen in end-on view at my level, and when observed below my level. There is nothing *a priori* improbable in flapping being confined to the hind wings. Beetles habitually keep the front wings at rest when in gliding flight. Sometimes while the hind wings are flapping there is a slight appearance of tremor of the front wings. I have also formed the impression that during the period of flapping the dihedrally-up angle of the front wings is decreased. But as the flapping only lasts for a fraction of a second it is difficult to imagine that I could see this change and distinguish it from a flap. But the possibility is obviously suggested that it occurs and is an adjustment

¹ Erhard in "Der Flug der Tiere," published in "Verhandlungen der Deutschen Zoologischen Gesellschaft" for 1913, page 206, gives the following rates of wing beat for different insects:

Dragon-fly	..	..	..	28	per second.
Common white butterfly (<i>Pieris repæ</i>)	..	..	..	9	"
Bee	..	..	..	190	"
House fly	..	..	..	330	"

The above rates of beat were probably obtained on insects held in a recording apparatus. In the case of dragon-flies this rate of beat probably occurs in fully unsoarable air. I have seen a large dragon-fly belonging to the *Genus anax* which at every few metres made a few beats at a rate that cannot have been more than two or three per second. This observation was made in Calcutta in sunshine and in moderate wind.

employed to prevent rotation upwards round the transverse axis during the flapping.

Occasionally in gliding flight the dragon-fly shows a jolt forward at increased speed. In some cases I believe that this jolt ahead is due to unrecognised flapping. In some cases only occurring in soarable air the jolt ahead seems to be initiated by a slight downward dive. The dragon-fly appears to glide downwards to the extent of perhaps $\frac{1}{2}$ in., and during the next few inches of its glide gradually regains its original height. In one case I noticed a dragon-fly gliding up-wind in an undulating up-and-down course. The undulations were several inches in height, and the distance from the top of one undulation to the next was about 2 ft. The insect was not simply being lifted and dropped by up-and-down movements of the air, as each downward glide was seen to be initiated by a transverse axis rotation.

Whatever may be the cause of these jolts, it would appear that the amount of movement produced is out of proportion to the adjustment, in the same sense as the amount of movement initiated by the double-dip of a vulture cannot be explained by the muscular action of moving the wings. In the case of the vulture, the adjustment is one that, in some unknown way, renders more air energy available. It remains to be seen whether a similar partial explanation can be applied to the jolts of the dragon-fly.

I attempted to obtain looking-glass records of these jolts, as shown in fig. 97. For obvious reasons it was a matter of great difficulty to obtain any record at all. The time intervals I was able to use were far too long to allow the suddenness of the forward jolt to be appreciated. The tracks I succeeded in obtaining were,

in all probability, cases of comparatively slow gliding. It is interesting to notice that the variations in speed were greater than variations in wind velocity, indicated by the record of the path of a piece of thistle-down, shown in the same diagram.

In two or three cases I have seen flapping of one hind wing while the other three wings were at rest, and while the insect was on a level keel. Although I failed to see that this produced any steering action, the observation obviously suggests that steering to right or left may be produced by beats of one hind wing. On the other hand, I have already stated that canted steer-

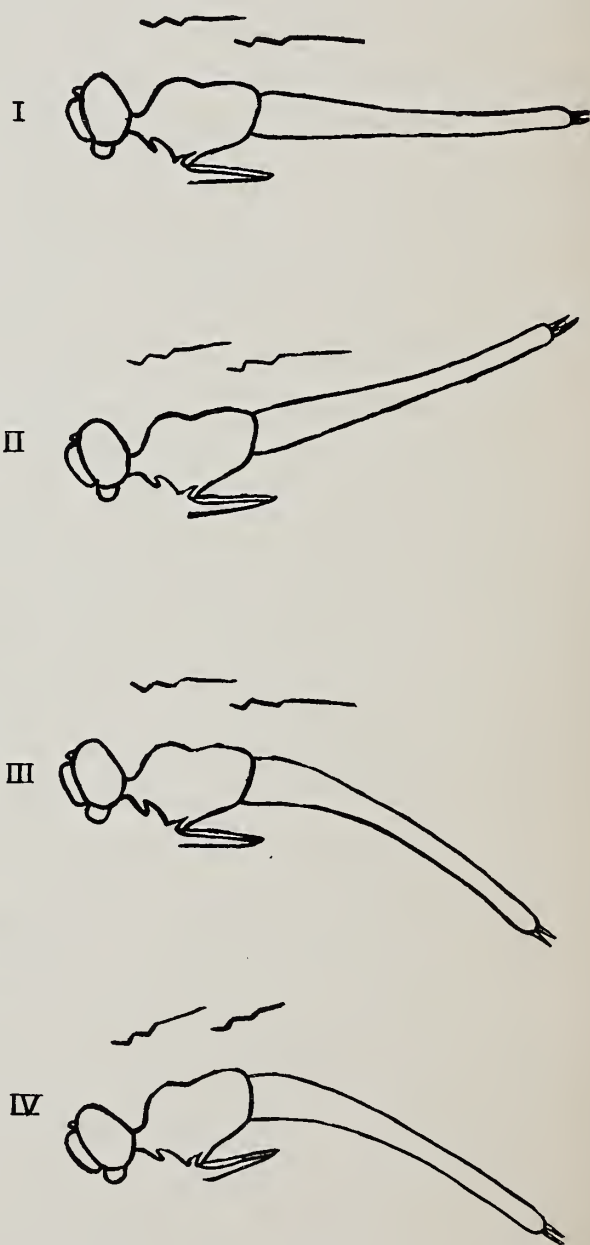


FIG. 95.

Diagrammatic side views of a Dragon-fly (*Pantala*) in horizontal gliding flight in air of differing degrees of soarability. The wings are shown in each case in section.

- I. With abdomen horizontal.
- II. With abdomen elevated.
- III. and IV. With abdomen depressed.

ing may occur without flapping. In view of what has been stated in previous chapters, it is clearly probable that this movement was produced by retirement, accompanied by rotation of one or both of the wings of one side. That is to say, it is suggested that

the dragon-fly may have two methods of steering to right or left, namely one by increasing the speed of the outside wing not accompanied by canting, and the other by decreasing speed of the inside wing accompanied by canting. But obviously further research is required before it can be definitely stated that dragon-flies resemble birds in having two methods of steering in the horizontal plane.¹

Dragon-flies may be seen just after sunrise and just after sunset in hurried and continuous flapping flight. In these cases all four wings are flapped and the speed is high. I have seen gentle flapping of all four wings while a dragon-fly was settling, and also in the case of dragon-flies liberated under a mosquito curtain and exposed to a wind. Under these conditions the insects always flew up-wind and showed no trace of gliding flight. I can state with confidence that the species of dragon-fly that I have observed at sunrise and sunset flapping with all four wings is the same species that I have observed in slower flap-gliding flight or in prolonged gliding flight during the daytime. A rare and very large species of dragon-fly, with green thorax and a white band on the abdomen, flaps with all four wings, so far as I have observed, during the day at times when it is not indulging in gliding flight.

The dragon-fly being an expert in gliding it is of interest to examine the structure of its wings. In fig. 96 I have shown the chief ribs or nervures of the fore wing. The small nervures that divide the surface of the wing membrane into small polygonal areas are

¹ Evidently, if my observations of the flight of dragon-flies are correct, these insects must have the power of rotating their wings. Two muscles capable of rotating the fore wing of the dragon-fly are mentioned in "Textbook of Entomology," by Packard (Macmillan), Vol. I., London, 1898, page 157. A case of observed rotation of one front wing causing a steering movement with canting is mentioned at the end of this chapter. The rotation was accompanied by depression of the wing. Hence it would appear that the two wings of one side must momentarily have functioned as one heavily cambered wing.

omitted for the sake of clearness. Near the centre of the front edge of the wing may be seen a peculiar transverse nervure (the "nodus"). This is curved up and down in a direction at right angles to the plane of the wing, so that it holds the different longitudinal nervures at different levels. Hence the membrane of the wing does not lie flat but is divided into ridges and troughs. The hind wing has a similar structure. This irregular surfacing of the wings is indicated in fig. 95, where sections of the wings are shown taken at about their middle points. Thus we find ridges transverse to the



FIG. 96.

Fore-wing of Dragon-fly (*Pantala*)
showing the principal nervures.

line of flight to be present in the wings of an insect of exceptional powers of gliding. These ridges form a strong contrast to the smooth and polished under surface of the wing of a night-flying moth.¹ In the case of the flying-fish transverse ridges are present on the under surface only. In the case of the dragon-fly, ridges are present on both surfaces of the wing.¹

Having described the flapping flight of dragon-flies, we now have to consider in more detail their gliding flight.

Dragon-flies can glide for very long distances. In sunshine, and in a place sheltered from the wind, and at a height of two to three metres above ground level, it is a matter of common observation for dragon-flies to glide without flapping or apparent loss of height for twelve or more metres. On the other hand after

¹ An illustration showing the ridges of the wing of a dragon-fly is included in an article by Mr. G. Howard Short, entitled "A Study of Natural Wings," published in *The Aero* for April, 1912, page 91. Those species of dragon-flies whose flight consists chiefly of flapping have ridges in their wings similar to those in the wings of the species whose flight consists chiefly of gliding. In many Orthoptera the wings of dried specimens at least are somewhat similarly ridged. How far such ridges persist during flight I am unaware.

sunset dragon-flies of the same species may occasionally be seen flying together in a group at comparatively low speed. Under these conditions the length of glide without flapping was usually from 4in. to 6in. In view of the clumsy shape of the body and their light weight the shortness of the glide under these conditions is perhaps not surprising. Periods of flapping (of the hind wings only) occurred at the rate of five such periods in three seconds. This flap-gliding flight was not productive of high speed. Hence it was easy to observe and was in strong contrast to the rapid gliding flight with less frequent periods of flapping observed in soarable air.¹

Two possibilities must now be considered: Firstly, it is possible that soarable air is for some unknown reason more suitable for gliding flight than unsoarable air. Secondly, it is possible that dragon-flies get energy from soarable air in the same unknown way as do soaring birds.

In view of the fact that the gliding flight of dragon-flies is usually frequently interrupted by short periods of flapping it might seem impossible to distinguish between these two alternatives by direct observation. Further, in view of their lightness and small size one would expect dragon-flies to be liable to be affected or lifted by air irregularities that are too small to have any effect on a soaring bird. I have occasionally seen dragon-flies when gliding up-wind make a vertical gain of height of several inches. It is impossible to prove, in any given case, that this gain of height was not due to some local ascending current. Cheels when lee-looping sometimes make a vertical gain of height as they turn

¹ In fully unsoarable air and especially in the absence of wind gliding is completely absent and the flight is maintained by continuous flapping of all four wings. This I have observed in Calcutta in the same species of dragon-fly (*Pantala*) as I had observed in Agra.

round to face the wind. This occurs when the gliding speed of the cheel happens to be the same as the speed of the wind. The cheel in reality is gliding upwards through the air at a very small angle with the horizon. The speed of the cheel through the air happens to be the same as the speed of the air over the earth. Hence there is a vertical gain of height. The gain of height occurs regularly at each loop of the lee-looping. It is not reasonable to suppose that vertical currents are regularly disposed at equal distances. Hence the explanation here given is reasonable. But in the case of the dragon-fly the gliding flight is less regular, and no such argument can apply. On two occasions in calm air and at a few feet distant from me at my own level, I have seen a dragon-fly glide upwards, at an angle of about 45° , for a distance of a few inches and without visible loss of speed. If it is asserted that these cases of gain of height were due to ascending currents and that dragon-flies are lifted in this way when they meet ascending currents then it appears to follow that ascending currents capable of lifting a dragon-fly are extraordinarily rare in a calm atmosphere. As is about to be shown it is only in calm air that dragon-flies give indubitable proofs that they take energy from the air. Perhaps it is not superfluous to state that by "calm" air I mean air that is destitute of wind not air that is destitute of motion. I have already shown that calm air in the morning contains ascending currents caused by the heat of the sun. These currents have no visible effect on dragon-flies.

But the problem can be attacked in another way. If dragon-flies get energy from the air in the same way as a soaring bird then they should only be able to glide

for long distances at times when the air is soarable for birds. Further one would expect them to avoid ascending currents (of a sufficient strength to affect their flight) when the air is soarable, and to take advantage of ascending currents when the air is not soarable, as is the case with birds. In the case of birds we have seen that instability is, as a rule, produced by irregularities in soarable air in some way connected with the cause of soarability, whatever this may be. Therefore it is necessary to see whether dragon-flies show instability and whether this instability shows any relation to changes of soarability. Lastly we have seen that the soaring flight of birds is sometimes aided by the presence of wind and that sometimes the presence of wind is unnecessary. We shall have to see whether wind has similar contradictory relations to the flight of dragon-flies under different conditions.

It is not always easy to find one's self in a position in which it is possible to observe birds and dragon-flies at the same time. But during a visit to Futteypur-Sikri I was able to do this satisfactorily as shown by the following extracts from my diary :

6th September, 1912, at Futteypur-Sikri. At 8.30.—Vultures arriving and flap-gliding in ascending current on windward side of hill. Cheels were already gliding in this ascending current. (Vultures do not take advantage of ascending currents reflected up from buildings in Agra as do cheels. In the present case they were in the ascending current reflected up from the side of a hill more than three miles long.)

9.30.—Thin nearly uniform cloud. Slight sunshine. As the sun came out, birds left the ascending current, and were seen circling to a height and drifting to leeward. Dragon-flies (*Pantala*) also appeared, and were seen gliding with occasional momentary flaps at various places on the leeward side of the hill. Some near the top of the hill (in a place more exposed to the wind) were gliding for the most part to leeward of trees.

12.0.—Increase of cloud. Birds returned to the ascending current on the leeward side of the hill. A few dragon-flies only were visible. They were travelling from place to place, and were in flapping flight.

In the above case it is interesting to notice that dragon-flies ceased their gliding flight not late in the afternoon, as usual, but in the middle of the day, when owing to the presence of cloud soarability suddenly decreased.

7th September, 1912, at Futteypur-Sikri. At 2.45.—There had been a storm in the night. This was now clearing off, and there was a strong glare of light with occasional sunshine. Vultures were circling. Dragon-flies were gliding in groups to leeward of trees below the leeward crest of the hill. They generally carried the abdomen horizontally, but it was slightly elevated when they got to one side out of the shelter of the tree and as speed through the air probably increased. There was an occasional period of flapping lasting for a fraction of a second, especially at the moment of a change of course. No lateral instability was seen.

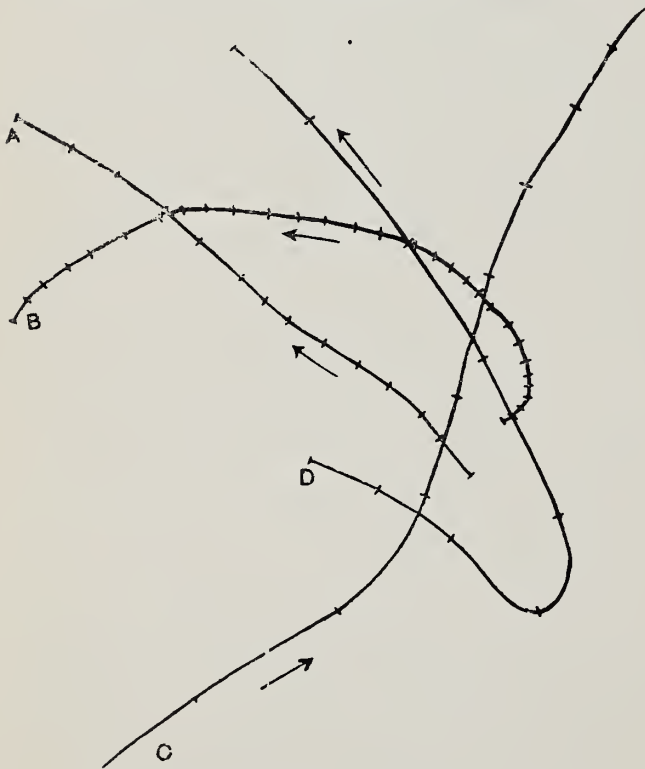


FIG. 97.

Looking-glass records of tracks of

- a. A piece of thistledown 3 metres up.
- b. A vulture at about 300 metres height.
- c and d. Dragon - flies in gliding flight at heights of 3 to 4 metres.

All records taken within two minutes of each other to leeward of a tree. Sky cloudless. Wind occasionally moving small branches. Times marked at the rate of $2\frac{1}{3}$ per second. September 15th, 1912.

2.48.—All dragon-flies in sight showing lateral instability.

3.0.—A black vulture flap-gliding up-wind at low level was showing lateral instability.

3.2.—A lull in the wind. Dragon-flies left the trees, and were seen in fast flapping flight.

3.4.—Less glare. No birds seen up.

In this case a sudden appearance of instability of dragon-flies immediately preceded a decrease of soarability of the air for birds besides a corresponding change in the mode of flight of dragon-flies.

8th September, 1912, at Futteypur-Sikri. At 7.35.—Fine. Wind occasionally moving leaves. Dragon-flies in flap-gliding flight.

8.20.—Cheels flap-gliding only.

8.59.—Cheels commencing to circle.

9.3.—Dragon-flies gliding. This was to leeward of hill.

9.6.—A black vulture circling.

10.57.—At leeward side of dawk bungalow. Dragon-flies gliding. Two seen attached to one another. The upper one had wings at rest, and more dihedrally-up than usual. The lower dragon-fly was in continuous flapping flight. This was seen both with the naked eye and with the binocular. The wings of the upper dragon-fly showed a positive angle of incidence.

3.45.—No birds up except a vulture circling at 1,000 metres and a cheel circling at low level, and then gliding up-wind with loss of height. Wind moving leaves. Dragon-flies left the trees to leeward side of hill, and came to sloping ground on windward side of hill, where they remained gliding in the ascending current. Many were seen arriving. One showed momentary flapping, immediately followed by lateral instability, which lasted for about half a second.

3.50.—A vulture, about 500 metres distant, and at a height of about 200 metres, was circling with wing-tips up, and appeared yellow. It rotated its wing-tips down, and immediately appeared white. It lost height, and settled.

5.2.—Dragon-flies in ascending current now showing much lateral instability of slight range—that is to say, rapid but slight lateral oscillations.

5.15.—In Diwani-Am (an enclosed courtyard) dragon-flies showed nearly constant flapping.

In this case as soon as a decrease of soarability at low levels was indicated by birds, dragon-flies ceased gliding on the leeward side of the hill and either came to the windward side and took advantage of the ascending current or indulged in nearly continuous flapping flight.

In the above instances dragon-flies only employed gliding flight at times when the air was soarable for birds. In view of the long distances to which they can glide in soarable air and the short distances that

they glide in unsoarable air, there is a presumption that they obtain energy for their flight after the manner of soaring birds.

But the matter is not so simple as is indicated by these considerations. The above observations were carried out in more or less disturbed weather at the beginning of September. Towards the end of that month, as the weather cleared up, another phenomenon was noticed. Between ten and eleven o'clock in the morning a change was observed to take place in the flight of dragon-flies. Up to about nine o'clock they had been seen in flap-gliding flight with the abdomen horizontal and making only short glides. From about nine o'clock to about ten o'clock they were making long glides with abdomen elevated (see fig. 95). But at some time between ten and eleven o'clock they were observed to have their abdomens hanging down and the gliding was interrupted by frequent periods of flapping. On making an excursion in a motor every group of dragon-flies seen on the road before this time had abdomens elevated. Every group seen after this time had abdomens hanging down. That is to say we are dealing with a widespread change in the condition of the air. Flight with abdomen hanging down continued till about three o'clock in the afternoon. Then abdomens again were elevated and longer glides were noticed until later, when the air again became unsoarable.

Thus it appeared that air soarable for birds might be suitable for one or other of two very different modes of flight of dragon-flies. But on further experience, I found that my impression that flight with abdomens hanging down involved frequent flapping, was merely due to my having in the first case observed it in the

morning and in the presence of wind. In the morning in the absence of wind dragon-flies with abdomen hanging down may make very long glides.

In the case of birds I have already shown that wind may have opposite effects on soaring flight under different conditions. In disturbed weather "wind soarability" occurs in which wind is indispensable for soaring flight. In fine weather, on the other hand, wind is unnecessary for soaring flight. The fact that hill crows only circle with gain of height in calm is a fact that suggests that wind in fine weather is actually harmful to the soarability of the air.

The facts about to be described show that the flight of dragon-flies bears exactly the same relation to wind. In disturbed weather in a wind I have seen dragon-flies (within 2ft. or 3ft. of me) maintain their position over the earth when struck by a puff of wind. That is to say they must have glided through the air of a gust at a greater speed than they did through wind in the absence of a gust. Similarly birds when struck by a gust may not only maintain their speed ahead relatively to the earth but even increase it. On the other hand, in the morning in fine undisturbed weather and in bright sunshine dragon-flies glide in calm but show periods of flapping when struck by wind. My first observation of this fact was made in a dry tank on the Sekundra Road, Agra. This tank has stone walls about six metres high. When sitting on the edge of the tank I noticed that dragon-flies, generally below but sometimes above my level, made long glides in apparent calm, but that as soon as a gentle breath of wind was perceptible just enough to be felt their flight was interrupted by frequent periods of flapping. I also noticed this.

difference at the bottom of a ravine and also over a level road and in a grassed enclosure. This difference in the mode of flight in the absence and in the presence of wind occurs both with abdomen hanging down and with abdomen elevated.

Between the 12th September and the 20th October I made observations on the position of the abdomen on twenty-seven days. In each case the abdomen was observed to be down in the middle of the day, with the following exceptions: From the 25th to the 27th September, when there was cloudy weather with some rain. On the 13th and 14th October, when weather was fine. On the 13th October I happened to note that there was some cirro-cumulus cloud. On the 17th October abdomens were down in the morning up to 11.25 in the presence of cirro-cumulus cloud, but generally raised from 11.30 onwards, when it was noticed that the clouds were dissolving. In the afternoon abdomens were down till 3.3, and from this time onwards were raised. At 2.27 I noticed vultures flex-gliding at exceptionally high speed. At 5.1 there was a slight dust-storm. On the days on which abdomen was down, weather was fine with cloudless sky.

The above observations suggest that clouds too thin to have any visible effect on the soaring flight of birds may affect the soaring flight of dragon-flies. The following observations definitely show that this is the case:

1st June, 1913. At south-west corner of Eden Gardens, Calcutta.—Wind south, moving small branches, and moving them strongly during occasional puffs. Sky covered with small fast moving cumulus clouds, mostly with ragged edges. Only slight shade was produced when a cloud was over the sun. A group of dragon-flies (*Pantala*) were keeping more or less to leeward of a tree, gliding up-wind for a short distance during lulls. They showed no lateral instability, but slight swaying from side to side when gliding against the wind.

11.20.—Sunshine. Dragon-flies making long glides with occasional flaps of hind wings. They had the thorax horizontal, and the abdomen hanging markedly downward. The folded legs were seen hanging down away from the abdomen, and were seen to remain so for long periods. I could not determine whether they were constantly in this position.

11.21.—Shade from cloud shadow. All dragon-flies gliding with abdomens horizontal.

11.22.—Sunshine. Dragon-flies gliding with abdomens down.

11.23.—Shade. Abdomens up. Legs also seen up.

11.25.—Sunshine. Abdomens down.

11.40.—Shade. Abdomens sometimes up, with thorax inclined downwards. Others seen with abdomens horizontal and more frequent periods of flapping.

11.44.—Sunshine. A short time after the sun came out, abdomens were seen to be hanging down.

11.46.—Sunshine. More wind. Very rapid flight difficult to follow, but apparently the dragon-flies were making very long glides.

11.47.—Shade. Abdomens horizontal, and frequent flapping. Less wind.

I made several other observations of similar changes in the position of the abdomen in correspondence with sunshine or shade.

10th July, 1913, at 12.15. On Strand Road, Calcutta, to leeward of a large tree. Wind S.S.W. moving small branches. Sunshine. Isolated cumulus clouds. No high level cloud overhead. Pantalas gliding with abdomens down. Legs seen to be permanently and markedly down. The Pantalas often made long glides without a flap, especially when at a height.

12.25.—Cloud shadow. Abdomens seen to be up, but the dragon-flies were still making long glides.

12.27.—Sun came out. The edge of the cloud shadow was sharp cut. Dragon-flies began to glide with abdomens down 27 seconds after the cloud shadow had passed off.

In one case in Agra I noticed that dragon-flies with abdomen hanging down and near tree-top level appeared to be able to glide without flapping so long as the air was calm for indefinite distances. On one occasion in calm I followed (with my binocular) a large green dragon-fly gliding without any trace of flapping flight. I continued to watch it until my arms were tired of holding up the instrument without seeing a single flap. It was gliding to and fro over a course of about forty or fifty metres without loss of height. Its flight was regular.

Had there been flapping there would have been jolts ahead, and I should have had considerable difficulty in keeping the insect in the field of view. As a matter of fact, no difficulty of this sort occurred. This species of dragon-fly glides with abdomen horizontal and wings apparently flat. The hind wings are certainly flat, but the front wings may possibly have a slight dihedral angle. A few minutes before making this observation wind had been gently moving the leaves, and this dragon-fly had been seen in flap-gliding flight.¹ In Calcutta I have observed glides of indefinite length of two species of dragon-fly. This also occurred in calm air, and is described in the last paragraphs of this chapter.

The following extract from my diary illustrates the influence of wind on the common species of dragon-fly. The observations were made in Jeypur House Compound, Agra. The ground was covered with grass, a few bushes, and some trees. To windward of me the ground was open and free of trees :

20th October, 1912. At 9.10.—Leaves still. No wind perceptible. Dragon-flies (*Pantala*) flap-gliding and making short glides. Abdomen carried horizontally when 1 metre above the ground or less. Abdomen elevated at heights of 2 to 3 metres.

9.36.—Dragon-flies at 2 to 3 metres height occasionally making longer glides.

9.45.—At 2 metres height flap-gliding. At 3 metres height glides of 3 metres seen. Eagles starting.

9.53.—Wind now very slightly moving leaves, and perceptible. All dragon-flies in sight frequently flapping.

9.58.—Calm. Dragon-flies making long glides.

10.0.—Calm. Glides seen up to 3 metres length.

10.1.—Glide measured of 4 metres length.

10.3.—Wind perceptible. All dragon-flies flapping.

10.8.—Calm. Dragon-flies making long glides and showing slight lateral instability.

10.9.—Vultures beginning to circle.

¹ The wings of this species of dragon-fly (probably *Hemianax ephippiger*) are comparatively opaque, and therefore easy to see. My doubt about the dihedral angle of the front wings is due to the fact that I have not yet observed this insect flying at my level. This dragon-fly has a span of 4 in., its weight is .68 gramme, and its loading is .066 lb. per square foot.

10.17.—Calm. A dragon-fly twice showed a steep gain of height without flapping. It glided up nearly at 45° for 3in. or 4in. No loss of speed observed. Dragon-flies at 2 to 3 metres height had abdomen elevated, and were making long glides. Dragon-flies below 2 metres height above the ground showed frequent flapping with abdomen horizontal.

10.20.—A puff of wind from north moving leaves. All dragon-flies in constant flapping flight. A few seconds later air calm, and dragon-flies seen a few metres to leeward making long glides.

10.26.—A black vulture flap-circling and then circling at 40 metres height. It showed very slight lateral instability.

10.29.—The black vulture was now circling at 100 metres height. Since 10.26 the centre round which it was circling had moved about 50 metres to leeward.

10.32.—Dragon-flies gone, except one seen at a distance.

10.47.—On Sekundra Road. Dragon-flies at 5 to 7 metres height making very long glides. Turns seen without flapping.

11.12.—One dragon-fly in sight. Abdomen down.

11.23.—Wind occasionally moving leaves. When at high levels abdomen horizontal, and long glides seen. At low levels shorter glides, and abdomens down.

11.26.—All dragon flies had abdomens down, and were making long glides.

These and other similar observations were carried out on dragon-flies that were, in most cases, within a few feet of me and sometimes gliding just over my head. Thus I was in the best possible position for observing the harmful effect of wind on developing soarability. In view of the lightness of the wind in the above cases it is impossible to imagine that the change in the mode of flight observed was due to the insect taking measures to prevent its being blown to leeward. In fully soarable air, especially in disturbed weather, the dragon-fly can glide against far stronger winds.

When *Pantala* is seen flying at sunrise or sunset with flapping of all four wings the flight is fast and irregular. After sunset these dragon-flies may be seen in this form of flight flying a few inches above the ground haunting the neighbourhood of a lamp-post and probably in search of prey. Similar four winged flight may be seen during the daytime under heavy cloud

both in the presence and in the absence of wind when, as shown by the movements of cheels, the air is completely unsoarable after a shower of rain. This rapid flight is solitary. On other occasions more or less continuous flapping of the hind wings only may be observed. When in a group in what appears to be unsoarable air *Pantala* may indulge in flap-gliding flight with four inch glides. Under other conditions the same or even a less amount of flapping is seen to result in glides of increasing length. If this usual amount of flapping of the hind wings is regarded as giving sufficient momentum for a four inch glide, then if under other conditions the same amount of flapping is followed by a glide ten times as long carried out at much greater speed, then it is probable that some other source of energy, namely air energy, is involved. If the air has sufficient soarability to permit of one or two metre glides between the flaps with abdomen horizontal, then other dragon-flies in the same group may be seen with abdomens elevated gliding without flapping at slightly lesser speed but for greater distances. These glides without a flap may be of any length between one and twenty metres. The longer glides are recognised more easily and apparently occur more often in absence of wind. In air of a higher degree of soarability *Pantala* may be seen gliding for still larger distances with abdomen and legs depressed, while another species of dragon-fly (*Rhyothemis*) may, under certain conditions hereafter described, glide at much lower speed than *Pantala* and with abdomen elevated. On two occasions in Calcutta I have seen evidence of a still higher degree of soarability in that both *Pantala* and *Rhyothemis* had the abdomen depressed and the glides

in the case of *Pantala*, on one of these occasions, were noted to be of indefinite length. In Calcutta during July and August it has rarely happened (as compared with Agra in September and October) that the sky has had that freedom from high level clouds that I have been led to associate with gliding with lowered abdomen, and this form of gliding has not often been observed. This list does not exhaust the number of the different states of the air revealed by the flight of dragon-flies. The curious lateral instability sometimes seen in Agra has not yet been observed by me in Calcutta, at any rate not to a degree readily recognisable. I have heard of dragon-flies in the Himalayas being seen flapping with the wings of the two sides alternately. It may be inferred that this was a case of lateral instability wrongly diagnosed. At Naini Tal I have seen slight lateral instability in several species of butterflies as they glided in ascending currents of air.

No more reason exists for assuming that the dragon-fly has a good gliding angle than in the case of birds. Observations of a few cases of dragon-flies making long glides in unsoarable air indicate that in such air a loss of height at the rate of one in four, or perhaps one in three, is necessary for this insect to maintain its gliding speed.

Despite the fact that my observations have led to no conclusion as to the effect of changes in the dihedral angle of the wings (which as I have seen may be different on different occasions), and though in other respects more remains to be learnt of the flight of dragon-flies, the facts already accumulated appear to justify certain conclusions.

Firstly, the cases of glides of indefinite length without loss of speed or height and with many changes

of course furnish a proof that the dragon-fly obtains energy for its flight from the air after the manner of a soaring bird. The singularly close parallelism between conditions affecting soarability for dragon-flies and soarability for birds, the avoidance of ascending currents when air is soarable, the reverse when air is unsoarable, by dragon-flies, and other facts above detailed, furnish further proofs that the gliding of dragon-flies depends on that regular and uniform condition of the air that I have described as soarability and not on chance currents of ascending air.¹

Secondly, it is probable that changes in the position of the abdomen play some part in altering the relation of the centre of gravity to the centre of effort of the wings in the same way as occurs in the case of movements of the tail of birds. It would be premature to speculate as to the exact nature of this relation. When flying with abdomen depressed dragon-flies may either carry the thorax as shown in fig. 95 III. or as shown in fig. 95 IV. I have seen both dispositions on the same day but at different times. Hanging down of the abdomen appears to indicate a higher degree of soarability. The parallelism between the soaring flight of birds and of dragon-flies is further shown in the fact that at the time when the change in the position of the abdomen is appearing dragon-flies at lower levels show the depressed position, while dragon-flies at higher levels are still gliding with

¹ I have elsewhere stated that there is reason for believing that the power of soaring flight was developed at an early stage in the evolution of birds. It is of interest that we should find evidence of a similar power of taking energy from the air in a type of insect that may be described as primitive. Some of the earliest known insects, from carboniferous strata, the *Protodonata*, differ but slightly in structure from modern dragon flies. From their structure and appearance it may be inferred that their habits were similar to those of dragon-flies as we know them. Whether or not their habits were so far similar that they could indulge in soaring flight must be left as an interesting possibility. The *Protodonata* differed from modern dragon-flies in that the "nodus" was absent from their wings, and in that the subcostal nervure was continued to the apex of the wing. Many of these primitive dragon-flies were larger than existing species. One of them, *Meganura monyi*, measured over 2ft. across the expanded wings. No existing dragon-fly has a larger span than 7in. True dragon-flies (*Odonata*) occur as far back as the *Lias*.

abdomen elevated. After the lapse of a further short time however, dragon-flies at all levels have the abdomen depressed, but soarability appears to be greater at a height as longer glides are seen near the tree-tops than near the ground. Similarly, on certain occasions, with birds in calm air in cold weather, while soarability is developing the air appears to acquire this property first at lower and later at higher levels. But at a later time in the day soarability for birds is found to be greater at a height than near the earth.

Thirdly, the decrease of sun soarability in the presence of gusts when the morning wind is developing furnishes a very complete proof that wind is not the cause of sun soarability. It has been suggested that soaring flight may be due to the bird being able to gain energy from turbulent movements of the air. The observations on dragon-flies indicate that turbulent movements, at least of a kind that could have visible effect on a piece of thistledown, instead of being useful are actually harmful for soaring flight.¹

Fourthly, it has been shown that if soaring flight is due to ascending currents these currents must be small in comparison with the span of a vulture. The facts now brought forward indicate that these assumed ascending currents must be small in comparison with the span of a dragon-fly.

Fifthly, we have seen that in the case of birds every minute portion of air behaves as if it were as ready as every other minute portion to furnish energy for their soaring flight. So far as the facts of the case are elucidated it appears that with dragon-flies also every minute portion of air behaves as if it were as ready

¹ See Wegener, "Ueber turbulente Bewegungen in der Atmosphaere," *Meteorologische Zeitschrift*, February, 1912, Vol. XXIX., page 49.

as every other minute portion to furnish energy for their flight. In each case these statements only apply to soarable air in which the animal is gliding without signs of instability.

If the energy of soarability is derived from ascending currents, or from separate masses of air of any other kind, one would expect there to be some lower limit of size for the gliding animal below which soaring flight would be impossible. This lower limit does not appear to have been discovered. As yet there is no reason for thinking that it has been approached in the case of the dragon-fly. But before finally deciding that it has not been approached further studies are required of the instability sometimes manifested in the flight of these insects.

But a further light is thrown on the matter by a study of the habits of a flapping dragon-fly that is common in Calcutta.

This dragon-fly is known as *Rhyothemis variegata*. It is of lighter build than *Pantala*. Its loading is .025 lb. per square foot. The loading of *Pantala* being .032 lb., and that of the large green dragon-fly (*Hemianax ephippiger*), apparently the most efficient of the three species as a glider, .066 lb. per square foot.

The greater part of the wing surface of *Rhyothemis* is of a bright yellow colour with black markings. It is easy to recognise when on the wing, and there is no other species in Calcutta with which it could possibly be confounded.

The flapping of *Rhyothemis* consists of isolated beats generally of all four wings, which may occur singly or in groups of two or three flaps, or occasionally of a dozen or more in rapid succession and at a rate

just too rapid to count. These groups of beats are separated by longer or shorter glides generally not exceeding a few inches in length. This form of flight may be described as "butterfly flight," as distinguished from the "buzzing flight" used by many insects including some of the smaller species of dragon-fly.

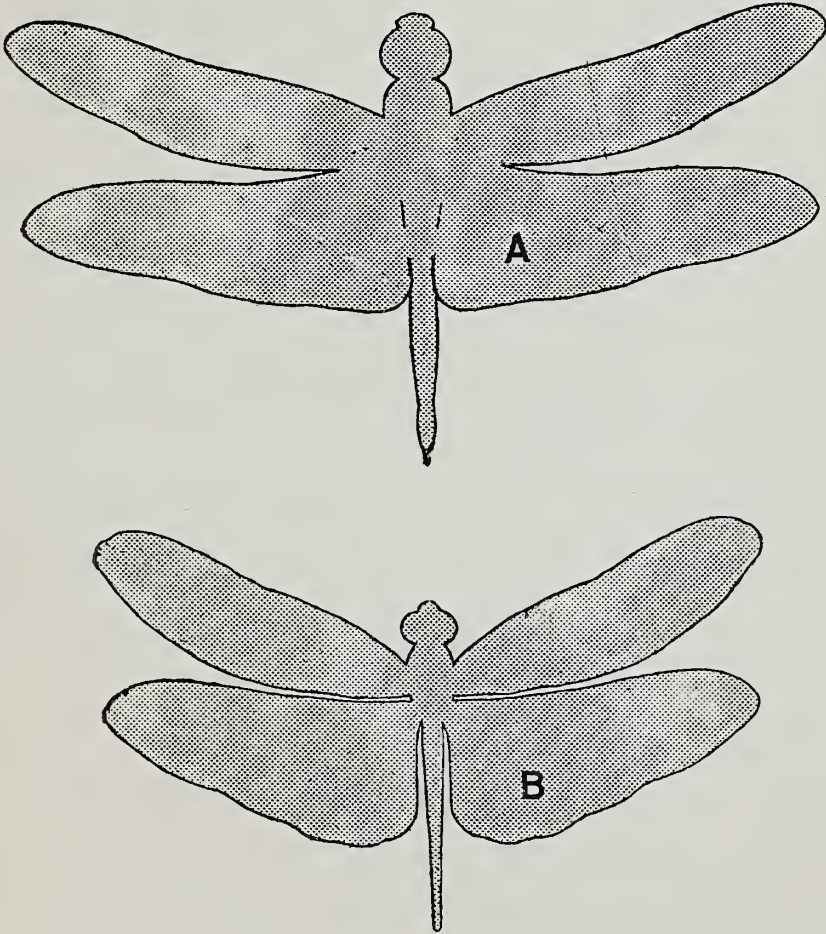


FIG. 98.

Outlines of dragon-flies (natural size).

A. *Pantala flavescens*.B. *Rhyothemis variegata*.

The dragon-flies of which we are now speaking frequently fly together in a group consisting of from a few dozen to a few hundred individuals. The group remains together for hours in the same spot. The individuals of the group keep somewhat close together, so that any cubic metre of the space occupied by the group is likely, at any moment, to contain from one

to three individuals. Their course is in general to and fro in a more or less horizontal direction from one side to the other of the group.

One or two specimens of *Pantala* may often be seen in a group of *Rhyothemis* gliding about with little or no flapping except, as a rule, at the moment after a sudden turn. On one occasion in the hot weather I noticed several *Pantalas* thus gliding in a group of *Rhyothemis*. At length a cloud came over the sun. The *Pantalas* immediately settled on some neighbouring telegraph lines, while the *Rhyothemis* continued their flapping apparently unaffected by the absence of sunshine.

It is noticeable that the *Pantalas* when gliding in a group with *Rhyothemis* travel at a much greater speed than the latter. That is to say, in the same air and within a few inches of one another one dragon-fly uses flapping in its flight. The other dispenses with flapping but nevertheless travels at perhaps double the speed. An upholder of the ascending current theory might devote much learned—and perhaps useless—casuistry to explaining why the swift-gliding *Pantala* finds these supposed ascending currents while the flapping *Rhyothemis* so consistently avoids them. The facts of the case contradict any theory that seeks to explain the gliding of *Pantala* by means of pre-existent movements in the air. Supposing that *Pantala* gets energy for its glides by meeting eddies, or from some mysterious aerial vibration, or from some turbulent movement of the air, why is it that *Rhyothemis* is unaffected thereby though a lighter insect?

Mr. Annandale, of the Indian Museum, Calcutta, made to me the ingenious suggestion that perhaps the object of the flapping of *Rhyothemis* is not so much

propulsion as to display its gaudy wings. The following observations appear to give some support to this hypothesis :

Occasionally *Rhyothemis* indulges in gliding flight with much less flapping than usual. The first occasion on which I noticed this phenomenon was in a small lane near Calcutta, in light wind and bright sunshine. Half a dozen *Rhyothemis* were in sight, not in a group, but at intervals of ten to twenty metres from each other along the lane. I saw one while gliding catch a small insect, glide with it for about a metre, and then let it fall. The insect fell vertically as if it had been killed. Dragon-flies have been supposed to catch their prey in the air, but, so far as I know, this has not previously been observed. These specimens of *Rhyothemis* were making glides of from one to three metres in length when in shelter and of one metre when gliding against the wind. Thus, in this case, the comparative lack of flapping occurred when the *Rhyothemis*, not being in a group, had no occasion to display their wings to each other.

Occasionally one or two specimens of *Rhyothemis* may be seen flying in a group of *Pantala*. Under these circumstances the *Rhyothemis* may make nearly as long glides as *Pantala* if the air is sufficiently soarable. That is to say it indulges in gliding flight when there is no opportunity of displaying its wings to other individuals of the same species. Once I noticed two *Rhyothemis* gliding in a group of *Pantalas*. Twice these dragon-flies approached each other, and on each occasion both individuals commenced flapping flight and continued flapping till they were some distance apart.¹ On another

¹ Contrary to the usual rule in insects, the female of *Rhyothemis* is far more brilliantly coloured than the male. The males also are far less numerous. The two *Rhyothemis* mentioned in the above observation were both females.

day I observed a *Rhyothemis* gliding in a group of *Pantalas*. Below it were two other *Rhyothemis* at about a metre height above the ground and both in flapping flight. One flapped upwards to a height of about three metres and then immediately began gliding. The following extract from my diary is of interest :

14th July, 1913. 12.5. On Napier Road, Calcutta.—Thin high level clouds over sky but hot and strong sunshine. *Pantalas* in a large group were making long glides with abdomens and legs down. In the group were three *Rhyothemis*, which also had abdomens down and were making long glides. One of these was seen to make a glide of over 20 metres in length and, as usual, without any visible loss of height. *Rhyothemis* were frequently observed to make canted turns without flapping, but in this species the turn is often so sudden that the canting produces a movement that might be mistaken for a wing beat. Adjoining the *Pantala* group was a large group of *Rhyothemis*. Individuals in this group were making frequent flaps, though one glide of about 10 metres in length was seen.

12.12.—Less sunshine. *Pantalas* were now seen with abdomens and legs up and making long glides. Occasionally they had abdomens horizontal and made shorter glides. *Rhyothemis* in both groups was in continued flapping flight.

5.30.—No sunshine but glare. Air quite unsoarable after a heavy rain shower. *Pantala* seen in fast irregular and jerky flight due to continued flapping of all four wings.

Thus the evidence goes to show that the flapping of *Rhyothemis* may on some occasions be partly due to a desire to display its wings to other individuals of the same species, but at the same time there can be no doubt that *Rhyothemis* (in view of its low speed besides other reasons) is less efficient than *Pantala* in getting energy from the air. The cause of this difference of efficiency obviously can have nothing to do with pre-existing air movements such as ascending currents. It must be sought for either in the lighter loading or in some other feature of the structure of the wing of *Rhyothemis* that makes it less efficient in liberating and using the energy stored in the air.

An interesting feature of the flight of *Rhyothemis* is that occasionally, and in fully soarable air, it appears to show what I first thought were signs of transverse axis instability. For reasons which will be obvious to those who have read preceding chapters, I have been on the look-out for this phenomenon in the flight of dragon-flies, and was interested to observe it, as I thought, in the flight of *Rhyothemis*. But this insect in fully soarable air sometimes shows "half-flaps." Some of these half-flaps are of very small range, so much so that at present it appears to me to be probable that the appearance of transverse axis instability is due to rudimentary half-flaps of the hind wings. In other words, we may be dealing with "anticipatory movements" such as occur in the flight of cheels and parrots.¹

Owing to the colour of its wings and the slowness of its flight flapping in *Rhyothemis* can be very easily recognised. In the case of *Pantala* with its transparent wings it is often difficult to be sure whether it is gliding or flapping. Unless the conditions of observation are good and unless the eye is in sufficiently good trim to be able to get glances at least of the position of the legs isolated flaps can be easily overlooked. In *Rhyothemis* on the other hand even minute half-flaps of the hind wings can be recognised with ease. Hence the long glides seen in the flight of this insect in fully soarable air, when in company with *Pantala*, must convince the most sceptical of the reality of the fact that

¹ These half-flaps are of the hind wings only. *Rhyothemis* also, under other conditions, may make half-flaps of all four wings at once. Half-flaps of this nature do not produce any appearance of transverse axis instability. They cause the whole insect to rise and fall slightly. The undulations thus produced are much less than the undulations, described in an earlier paragraph, in the flight of *Pantala* in Agra, which undulations had the appearance of being due to some atmospheric irregularity. Why *Rhyothemis* should occasionally make half-flaps and why such half-flaps should sometimes be of two wings and on other days of all four wings, are matters for future investigation.

dragon-flies use air energy for their gliding flight in the same way as soaring birds.

Towards the end of August I have frequently seen *Rhyothemis* making longer glides, in fully soarable air, than was its habit during May, June, and July. Nothing is known as to its breeding habits. It is, however, probable that its chief breeding season is in June at the beginning of the monsoon season. The following examples of longer glides than usual may be quoted:

24th August, 1913. On Napier Road. 11.30.—A shallow barometrical depression now to west of Calcutta and filling up. Showery yesterday. Now fine. No high-level clouds. Sunshine at intervals. Fracto-cumulus clouds. Leaves still, and no wind perceptible during period of observation. Direction of smoke indicated that wind was between south and east.

A large group of *Rhyothemis* with a few *Pantala* observed.

A *Pantala* watched gliding with abdomen down and without flapping till my arms were tired. It was during this glide at a height of between 2 and 3 metres. *Rhyothemis* were gliding with abdomens up. They were making glides usually of several metres length without flapping. Occasionally still longer glides were observed. Their speed when thus gliding was less than that of *Pantala*, and they did not travel so far as *Pantala* without changing course.

A *Rhyothemis* seen with abdomen down and wings less dihedrally-up than usual.

11.59.—*Rhyothemis* were timed making glides without flapping of 4, 4, 5, and 15 seconds duration.

A dragon-fly of unknown species appeared. It was of unusually large size. Its wings were not coloured. Its thorax and abdomen appeared of black or blue-black colour. It carried its wings slightly dihedrally-up, and abdomen slightly elevated. It was in gliding flight. Two or three *Rhyothemis* chased it occasionally. They were flapping while so doing. While being thus chased it was seen to make a sudden turn to the right. During this turn the right fore wing appeared depressed and rotated downwards. That is to say, the hind margin of this wing was seen on a higher level than its front margin. At the time the dragon-fly was on my level.

12.5.—In strong sunshine, a *Pantala* seen making a long glide (perhaps about a hundred metres) at low level and with abdomen down. At the time most of the *Rhyothemis* were out of sight. A few near me were flapping at about 1 or 2 metres height above the road.

12.8.—The large dragon-fly seen at tree-top level. It was watched gliding without a trace of flapping till my arms were tired of holding the binocular. Its flight was slow as compared with *Pantala*, and it was easy to keep in the field of view. Its wings, besides being nearly

flat, were held in the straight position (*i.e.*, not advanced, as are the wings of *Rhyothemis* whilst gliding). This was in bright sunshine. By the time that my arms began to feel tired this dragon-fly was seen to flap momentarily every few metres. It was seen doing this for some minutes. On ceasing the observation, when the dragon-fly went out of sight behind a tree, the sun was found to be partially obscured.

This long flight was to and fro over a course probably a little over 50 metres in length. The dragon-fly was seen to become canted just before a turn. This turn, like other turns observed, was not followed by flapping.

Thus in Calcutta, as in Agra, glides of indefinite length without loss of height or speed have been observed in the absence of wind of appreciable strength.

But the above extract from my diary is especially interesting in that the sudden appearance of this unknown dragon-fly at length furnished a fact of observation in support of the view I had formed a year previously as to the mode of steering employed by these insects.

APPENDIX I.

GLOSSARY.

ABEAM.—A term applied to the direction of the wind indicating that it is blowing in a direction approximately at right angles to the direction of movement of the bird.

ADVANCED WING POSITION.—Imagine a bird gliding horizontally with wings extended. If the long axis of the wings forms a right angle with the long axis of the body, the wings are said to be in the "STRAIGHT" position. If the wings are then moved in the horizontal plane, in a forward direction, so that the wing-tips move in the direction of the head, then the long axis of the wing forms an angle less than a right angle with the front half of the long axis of the body. The wings in this position are described as "ADVANCED." If the wings are moved in the opposite direction (in the horizontal plane), so that the wing-tips are moved back in the direction of the tail, then the wings are said to be "RETIRED."

AIR—SOARABLE, UNSOARABLE.—Under some conditions the air is found to be capable of supporting soaring flight and is said to be "SOARABLE." In such air a bird can travel horizontally without loss of speed. Under other conditions air is incapable of supporting soaring flight and is described as "UNSOARABLE." Under such conditions a bird generally glides with a well-marked loss of height, that is to say, using the force of gravity to maintain its speed. Or during the glide there is a gradual and constant increase in the angle of incidence, that is to say, height is maintained at expense of momentum, and speed decreases.

ANGLE DIHEDRAL.—Two straight lines which meet at a point form an angle with each other. Two flat surfaces which meet along an edge form a "DIHEDRAL ANGLE" with one another. The wings of birds are considered as two such surfaces. In horizontal gliding flight the two wings may lie in the horizontal plane that passes through the bases of the wings. In this case the wing disposition is said to be "FLAT." The two wings may be lifted above the level of this plane. In this case the wings are said to make a dihedral angle with one another. It is preferable to say that the wings are "DIHEDRALLY-UP." Alternatively the wings might be lowered so that they lie below the level of the above-mentioned horizontal plane. In this case the wings are said to be "DIHEDRALLY-DOWN."

ANGLE OF INCIDENCE.—Take the case of a bird gliding horizontally with wings extended. For the sake of simplicity let us regard the wings as flat planes. In such flight the wings do not lie exactly in the horizontal plane. They are slightly tilted up

round their longitudinal axes so that the air strikes their under surfaces as the bird moves ahead. The amount of this tilt, that is to say, the angle made by the plane of the wing with the horizontal plane, is known as the "ANGLE OF INCIDENCE." It may in certain cases be preferably described as a "POSITIVE ANGLE OF INCIDENCE." In the form of flight known as "flex-gliding" the wing is rotated in the opposite direction, and may be described as having a "NEGATIVE ANGLE OF INCIDENCE." In this form of flight the bird is travelling horizontally. Imagine a horizontal plane that touches the anterior margin of the wings. Then the hinder part of the wings lies above this plane. If the hinder part of the wings lay below this plane, then the angle of incidence would be positive.

ANTICIPATORY MOVEMENTS.—Occasionally a bird may be seen to make minute movements of its wings too small to affect its flight, and which appear to be made in anticipation of larger wing movements that it is about to make.

AQUILINE WING SECTION.—See "Wing Sections."

ARCHING.—Concavity of the underside of the wing in the side to side direction is described as "ARCHING." The angle of incidence is small when the wing is arched, that is to say, smaller than it is when the wings of the same bird are not arched.

ATTRACTION WIND.—When a dust-storm is forming, the wind blows towards the centre of the storm from all directions. This wind is described as the "ATTRACTION WIND." After it has blown for some time, and as the storm approaches the observer, it is replaced by the "STORM WIND" or "DISPLACEMENT WIND," which appears to blow outwards from the centre of the storm in all directions. So far as I am aware, dust-storms with attraction winds only occur in the drier, hotter, and more desert parts of India. I have not once seen any sign of the attraction wind in connection with numerous thunderstorms that I have observed in Calcutta both in the hot weather and in the monsoon season. In the attraction wind there appears to be a rise of temperature (even in the absence of sunshine) and at the same time a decrease of soarability.

CAMBER.—Imagine a bird gliding horizontally with wings extended. The underside of the wing is found to be concave in the fore and aft direction. This concavity is known as "CAMBER." The wings of birds are so constructed that the camber is decreased by flexing at the carpal joint, and with sufficient flexing (as in fast flex-gliding) camber is abolished. In the larger bats (flying-foxes) part of the wing membrane is attached to the thumb. In flight with thumbs held horizontally the wings have little or no camber. If the thumbs are depressed camber is increased. In many of the smaller bats the wing membrane is not extended to the thumb and this mode of varying camber is absent. In flying-fishes a special muscle pulls down the first fin ray producing or varying the camber of the wing.

CANTING.—A bird is said to be “CANTED” when it has been so rotated round the longitudinal axis of the body that one wing is higher than the other. The term “BANKING” is used by aviators to describe a similar position of an aeroplane. But in the case of the aeroplane the amount of banking required is proportional to the speed. In the case of birds in soarable air, canting does not appear to be proportional to speed. At present therefore it is advisable to retain the term “CANTING” in connection with the flight of soaring birds.

CANTED FLEX-GLIDING.—Birds in soarable air when gliding horizontally at speed with wings flexed (= flex-gliding flight) usually travel on a level keel. That is to say, when seen in end-on view the wings appear to be level with each other and the body is not tilted to one side or the other. Occasionally, however, flex-gliding birds, when travelling with wind beam on, that is to say, when travelling in a direction at right angles to the wind, are seen to be slightly canted-up away from the wind. The windward wing is elevated and the leeward wing is depressed. That is to say, the whole bird appears to have been slightly rotated round the longitudinal axis. Birds may be observed thus canted flex-gliding in a straight line for miles. If one flex-gliding bird is seen canted, then every other flex-gliding bird in sight, provided it is travelling in a direction at right angles to the wind, will be found to be canted to the same degree.

CARPAL DESCENT.—This term is applied to a form of descent in which the wing is flexed at the different joints, especially at the carpal joint, to such an extent that the bird falls feet foremost through the air with no increase of speed ahead.

CIRCLING.—A soaring bird when wishing to gain height glides along a curved course in curves resembling circles. This form of flight is known as “CIRCLING.” “EASE-CIRCLING” is similar flight but with no effort to gain height. In the morning when soarability is developing, at the commencement of circling, the bird may find it necessary to flap at intervals. This form of flight may be described as “FLAP-CIRCLING.”

COVERTS OR COVERT FEATHERS.—The large feathers of the wing are known as quills. The bases of the quills on both the upper and under surfaces of the wing are covered with smaller feathers known as “COVERTS.”

DESCENT.—Several different wing dispositions are employed by birds when descending. In fully soarable air, vultures may be seen flex-gliding in different directions at a speed of 8 to 12 metres per second. Under certain unknown atmospheric conditions (noticed on many occasions, besides those mentioned in the text, to occur a few hours before a thunderstorm and in a cloudless sky) the speed is from 20 to 24 metres per second. If they then see carrion and flex-glide towards it with loss of height, their speed may increase to between 30 and 40 metres per second. Landing on the earth would be impossible at such speeds, and before landing can be accomplished speed

has to be reduced. If the bird is not in too great a hurry, it will flex-glide to a point 200 or 300 metres above the desired landing place. It then extends its wings, the extension being complete at the carpal joint. There is, however, a slight flexing at the metacarpal joint. This disposition results in the wings being given their full camber but an inappropriate angle of incidence. This results in loss of speed, and eventually to gradual loss of height. This form of descent may be described as "METACARPAL DESCENT." While thus checking speed the bird travels in circles. When the speed has been reduced to perhaps 3 to 6 metres per second, the vulture changes to "CARPAL DESCENT" by flexing the wings at the carpal and shoulder joints. The bird thus transforms itself into a sort of parachute, falling feet foremost through the air without increase of speed. As the bird draws near to the carrion the wings may be slightly extended to check the feet foremost fall, and the bird may be seen to glide ahead. Sometimes under these conditions the secondary quills may be seen to be flickering. As the bird nears its perch it advances the wings, thus causing rotation round the transverse axis, until the plane of the wings is nearly at right angles to the direction of movement. This adjustment is termed "STOP-DESCENT." It rapidly checks the speed ahead, enabling the bird to alight on its feet without difficulty. At the moment before alighting the feet are suddenly thrown forward to prevent the bird from falling over forwards as it reaches the ground. Supposing the bird is descending from a height in a hurry, it may make use of "SHOULDER DESCENT." In this disposition the wings, besides being flexed at the carpal and elbow joints, are retired at the shoulder joints. That is to say, the lift is brought backwards in relation to the centre of gravity. Consequently there is rotation downwards of the bird round the transverse axis, and it then glides downwards head first with increasing speed. In an extreme form of this disposition the wings are still further retired by movement at the shoulder joint so that the bird glides nearly vertically downwards. This may be described as "DIVING." A shoulder descent or a dive are both checked by placing the wings in the dihedrally-up position. This causes rotation round the transverse axis so that speed ahead is changed to speed feet foremost through the air. As speed then decreases (owing to the increased resistance) the bird gradually brings the wings back to the "flat" position, and now finds itself in "CARPAL DESCENT." Carpal may be distinguished, at the moment it commences, from shoulder descent by the fact that the latter is initiated by a slight transverse axis rotation.

DIGITAL QUILLS.—See "Wing Structure."

DIGITAL QUILL GAP.—This name is applied to a gap between the fourth and fifth primary quills that may occur momentarily at the commencement of a "dip" movement of the wing-tip.

DIHEDRAL ANGLE.—See "Angle Dihedral."

DIP MOVEMENT.—A movement in which the tip of the wing is seen to dip downwards is described as a "DIP MOVEMENT" or "DIP." It has been shown to be due to rotation of the wing-tip. In an ordinary dip movement both the digital and the metacarpal quill masses (see "Wing Structure") are rotated round the long axis of the wing and then appear to move downwards. A movement of lesser extent, in which only the digital quill mass is rotated, is described as the "HALF-DIP MOVEMENT" or "HALF-DIP." Either of these movements checks the speed ahead of the wing whose tip is rotated. These movements are consequently used in steering. In the "DOUBLE-DIP MOVEMENT" both wing-tips, and to some extent also the wings, appear to be momentarily depressed. This movement occurs in flex-gliding, and is followed by a sudden and unexplained increase of speed ahead. The "WINDWARD DIP" is a dip movement of the inside wing often observed at the end of the windward side of the circle in circling. The "LEEWARD DIP" is a similar movement occasionally seen at the end of the leeward part of the track.

DORSO-VENTRAL AXIS.—This is the axis which is vertical when the bird is gliding horizontally.

DORSO-VENTRAL AXIS INSTABILITY.—In this form of instability the bird rotates to and fro round the dorso-ventral axis.

DOWN STROKE.—The BEAT of the wing in flapping flight is described as consisting of an UP STROKE (in which the wing travels upwards) and a DOWN STROKE (in which the wing travels downwards).

DOWN WIND.—A direction with the wind or to leeward.

DRAG.—This is the resistance of the bird to passage through the air. In unsoarable air it consists of the resistance of the body and of the wings. In soarable air it consists of the resistance of the body and of the wing-tips (in circling), and of the body only in fast flex-gliding. If a bird is flying horizontally certain forces tend to bring its flight to an end. These are the weight and the drag. The resultant of these two forces has been described as the "TOTAL DRAG."

DROPPING TURNS.—When a bird is in carpal descent it may momentarily increase the flexing of one wing. This wing thereupon becomes lower in position than the other wing, or in other words, the bird becomes canted. This movement is generally combined with a slight turn round the dorso-ventral axis. This movement, during which one wing drops a short distance through the air as compared with the other wing, is described as a "DROPPING TURN."

DUST DEVIL.—A whirlwind in which a quantity of dust is raised into the air.

DUST STORM.—A small local storm in which the air has an extraordinary power of raising dust. In its typical form as described in the text it only occurs in the drier and hotter parts of the

plains of India. It occurs under those meteorological conditions that are favourable to thunderstorms.

EASE-CIRCLING.—Gliding on a circular course without effort to gain height. In this form of flight the wing-tips are less advanced than they are in circling with effort to gain height.

EASE-GLIDING.—In the morning while soarability is developing birds have to circle in order to maintain or gain height. As soarability increases they may still be able to maintain their height while gliding in irregular curves. This form of flight is described as "EASE-GLIDING." It is more frequently used by the lighter than by the heavier soaring birds.

EDDIES.—This term is applied especially to the upward movement of masses of heated air. The air movement is best seen by looking at horizontal lines on buildings through a binocular held firmly in a clamp. If these eddies are produced by the action of direct sunshine, they may be described as "SUN EDDIES." Another set of eddies come into existence towards sunset owing to the heated earth warming the air in contact with it. These may be described as "EARTH EDDIES."

EMERGENCY ADJUSTMENT.—When startled a bird may suddenly lower its legs and flex its wings so that it begins dropping through the air feet foremost. That is to say, in an emergency it may momentarily adopt the carpal descent wing disposition.

EVEN WING DISPOSITION.—If the wing in flight when seen from behind appears to lie in one plane and to show no arching, it may be described as "EVEN." The even and dihedrally-down wing disposition may be difficult to distinguish from slight arching in the case of cheels.

FALSE SOARING FLIGHT.—Gliding in which the bird takes advantage of ascending currents known to exist may be described as "FALSE SOARING FLIGHT." In such flight the bird remains in a restricted area in the position in which a high building must reflect the wind upwards. The height to which the bird is lifted depends on the strength of the wind, and is in all cases limited. It only occurs in the presence of wind. In true soaring flight, on the other hand, birds usually appear to take pains to avoid known ascending currents. Such soarability is not proportional to wind strength, but rather the reverse. The birds do not remain in a restricted area, and in many cases appear to glide horizontally for indefinite distances.

FLAPPING, HALF.—Occasionally birds may show wing beats of very limited amplitude, which are described as "HALF-FLAPS." It has been suggested that soaring flight may be due to undiscovered wing movements. Apart from the fact that small wing movements such as half-flaps can in themselves have only a very limited power of propulsion, the fact that soaring flight commences at a definite time of the day excludes this explanation. No reason could be given why a bird could make half-flaps or other limited movement after and not before a particular time.

FLAPPING, STOP.—Just before perching birds advance the wings, rotate round the transverse axis, and make a few flaps in which the wings move, not up and down, but in a fore and aft direction. This is described as “STOP-FLAPPING.” Its purpose is to check speed ahead.

FLAT WING DISPOSITION.—The wings of a bird are said to be “FLAT” when, if seen from behind, they are seen to lie in one plane and to have no dihedral angle.

FLEX-GLIDING.—This is the most important form of soaring flight. In this form of flight the bird travels at high speed horizontally with neither gain nor loss of height and for indefinite distances. It requires more air energy to be available than does circling, as shown by several facts. For instance, it is more easily prevented by thin cloud shadow than is circling. In this form of flight the wings are flexed, and in fast flex-gliding the angle of incidence is negative.

GLIDING. — See “Ease-gliding,” “Flex-gliding,” “Lift-gliding,” “Poised-gliding.”

HALF-FLAPPING.—See “Flapping, Half.”

HEADING.—In a strong wind, if travelling with the wind more or less abeam, a bird does not travel directly towards the point to which it wishes to go, but aims at a point somewhat to windward of its destination. For instance, its head may be seen pointing in a direction 45° off the wind, while its course is seen to be 90° off the wind. This is described as “HEADING.”

HEAT EDDIES.—See “Eddies.”

INSIDE WING.—When a bird is gliding in a circle, the wing nearest to the centre of the circle is described as the “INSIDE WING.”

INSTABILITY.—In completely unsoarable air a bird glides without any appearance of instability. In an ascending current, or when passing in and out of such currents if of unsoarable air, birds only show trivial signs of instability. Their wings are so rapidly adjusted for changes in the rate of ascent of the air that symptoms of instability can scarcely, if at all, be detected. In soarable air, on the other hand, birds show various signs of instability. “DORSO-VENTRAL AXIS INSTABILITY” is seen as a tendency to rotate to and fro round the dorso-ventral axis. “TRANSVERSE AXIS INSTABILITY” is a tendency to rotate upwards (not to and fro) round the transverse axis, that is to say, round a line that may be imagined running through the bird from one wing-tip to the other. It is combated by a movement described as “tail-jolting.” “LATERAL INSTABILITY” is seen as small rotations to and fro round the longitudinal axis.

JOLTING.—See “Tail-jolting.”

LATERAL STABILITY.—Reasons have been given for believing that a bird maintains its lateral stability, that is to say, it checks any tendency to oscillate round its longitudinal axis by slight advancing or retiring of one wing relatively to the other.

LATERAL INSTABILITY.—This is the term given to slight to and fro oscillations round the longitudinal axis seen in birds and other flying animals when gliding in soarable air. It has been shown to be due to a lack of homogeneity of the air, and occurs especially when soarability is either decreasing or increasing.

LEE-LOOPING OR LEEWARD LOOPING.—A form of circling flight in which, after describing each circle, the bird makes a long glide to leeward.

LEADING EDGE.—If a bird is gliding horizontally with wings extended, the anterior margin of the wing is called its "LEADING EDGE." The posterior margin of the wing is the "TRAILING EDGE."

LEEWARD.—A leeward position or direction is the position or direction towards which the wind is blowing from any particular point.

LEEWARD DIP.—A dip movement of the wing-tip of the inside wing in circling, that occurs at the end of the leeward portion of the track. It is not often observed, and probably does not often occur.

LIFT-GLIDING.—Gliding in an approximately straight line with wings fully extended and consequently at maximum camber is called "LIFT-GLIDING." This gliding may be either horizontal with loss of height or, more commonly, with gain of height. It is usually in an up-wind direction. It occurs in air in which the amount of air energy present is not sufficient for flex-gliding. The air energy in such air is very frequently not uniformly distributed. Hence lift-gliding is usually accompanied by signs of dorso-ventral or lateral instability.

METACARPAL DESCENT.—See "Descent."

OUTSIDE WING.—When a bird is travelling on a curved course, the wing furthest from the centre round which the bird is travelling is called the "OUTSIDE WING."

PRIMARY QUILLS OR PRIMARIES.—See "Wing Structure."

POISING.—This is a form of flight in which the bird remains in one position relatively to the earth with wings in rapid movement. It may occur in the absence or in the presence of wind.

POISED GLIDING.—This is flight in which a bird remains in one position relatively to the earth without any flapping movements of the wings. It can only occur in the presence of wind and in wind whose speed is equal to the gliding speed of the bird through the air.

PULL.—In flapping flight the force exerted by the wings may be regarded as consisting of two components, one of which tends to lift the bird, and the other of which tends to pull it ahead horizontally. The latter component is called "PULL." The term "TOTAL PULL" is applied to the total force exerted by the wings in flapping, or alternatively to the total force, tending both to lift and pull forward the bird, exerted by the unknown force of soarability when the bird is in soaring flight.

RELAXATION OF SECONDARY QUILLS.—The wing of a bird is so constructed that when it is fully extended the free ends of the secondary quills or secondaries are directed somewhat downwards when the bird is in horizontal flight. Thus the underside of the wings is concave or cambered. If the wing is now slightly flexed at the carpal joint, the ligaments holding the secondaries in position are relaxed, and the hinder edge of the wing is seen to lift. In this condition the secondaries are said to be "RELAXED."

RETIRED WING DISPOSITION.—See "Advanced Wing Position."

ROTATION.—Rotation round the transverse axis of the bird is said to be "DOWNWARDS" if it is in such a direction that the head end of the bird goes down and the tail end goes up. Similarly rotation of a wing or wing-tip is said to be "DOWNWARDS" if the anterior margin goes down and the posterior margin goes up. Rotation in the opposite direction is described as "ROTATION UPWARDS."

SECONDARIES.—See "Wing Structure."

SHOULDER DESCENT.—See "Descent."

SOARING FLIGHT.—This is gliding flight in which birds or other soaring animals appear in some unknown way to get energy from the air. This use of air energy is manifested either in gain of height as in circling, or in horizontal flight by maintenance of high speed over indefinite distances. See also "False Soaring Flight."

SOARABILITY.—The condition of the air that enables it to furnish energy for soaring flight. Soarability is of two kinds. "SUN SOARABILITY" only occurs in the presence of sunshine or when the sun is only covered by a thin layer of cloud. It only commences some hours after sunrise and ceases in the afternoon an hour or two before sunset. It may occur in the absence of wind. So far as is known this form of soarability is always present in inland places in sunshine with the above restrictions. The other kind of soarability is described as "WIND SOARABILITY." This may occur in the absence of sunshine, but only in the presence of wind. The amount of wind soarability present does not depend on the strength of wind. Some strong winds may be completely unsoarable. In such winds birds are unable to remain gliding in the air unless in the neighbourhood of a current reflected upwards from some high building, etc. In true wind soarability birds take pains to avoid such ascending currents, apparently owing to the fact that ascending currents formed thus in a soarable wind cause excessive instability.

SOARABLE AIR.—This is air in which birds are capable of indulging in soaring flight. See preceding paragraph.

STABILITY.—The stability shown by flying animals in gliding flight is probably, in most cases and for the most part, maintained by adjustments that are subject to nervous control. But in fast flex-gliding it is probable that the position of the wings, the direction from which the force of soarability acts, and the constancy of this force, result in stability without the assistance of voluntary or instinctive adjustments.

STOP-FLAPPING.—A form of flapping flight used at the moment of perching. In this form of flapping the beats are horizontally backwards and forwards. The wings are kept fully extended, instead of having the wing-tips slightly retired as in ordinary horizontal flapping flight.

STOP-DESCENT.—See “Descent.”

STRAIGHT WING POSITION.—See “Advanced Wing Position.”

STRIGINE WING SECTION.—See “Wing Sections.”

SUN SOARABILITY.—See “Soarability.”

TAIL-JOLTING.—Sometimes during flight the tail, whether expanded or furled, is seen to be suddenly and momentarily jolted upwards. This “TAIL-JOLTING” is used to prevent rotation upwards of the bird round the transverse axis.

TAIL-TOUCHING.—Flying-fishes when gliding over calm water sometimes at intervals lower the tip of the tail into the water. During this “TAIL-TOUCHING” the tail is wagged to and fro sideways. This sculling movement increases the speed of the fish through the air.

TELEMETER.—An instrument used for measuring distances.

TRAILING EDGE.—See “Leading Edge.”

TRANSVERSE AXIS INSTABILITY.—This is seen as a tendency to rotate upwards round the transverse axis. A tendency to rotate downwards round the transverse axis has not been observed. Transverse axis instability is usually seen, if at all, in highly soarable air, that is to say, in air in which lateral instability and dorso-ventral axis instability do not occur.

UNSOARABLE AIR.—This is air incapable of supporting soaring flight. It is most frequently seen in the absence of wind in cloudy weather after a heavy shower. In such air gliding dragon-flies (*Pantala*), if in flight, maintain a continuous flapping of all four wings, as contrasted with the gliding interrupted by short periods of flapping of the hind wings usually used by these insects in soarable air.

UNSOARABLE WINDS.—Some winds have the power of supporting soaring flight independently of the direct influence of sunshine. Other winds occurring perhaps more rarely are unsoarable. In rare cases winds of very great strength may be unsoarable. In such “UNSOARABLE WINDS” soaring birds either glide in ascending currents reflected upwards from buildings, or come to earth.

UP-STROKE.—See “Down-stroke.”

UP-WIND.—A direction to windward of any point.

VULTURINE WING SECTION.—See “Wing Sections.”

WINDWARD.—A windward position or direction is the position or direction from which wind is blowing towards any particular point.

WINDWARD DIP.—A name given to a slight rotation of the wing-tip of the inside wing of a bird which may occur at the end of the windward side of the track in circling.

WIND CANTING.—A bird when gliding against a wind is sometimes seen to rotate on its dorso-ventral axis and to become canted at the same time. After "wind canting" in this way it glides in a direction away from the wind and returns to a level keel. Wind canting is frequently seen in wind whose velocity is equal to the gliding speed of the bird, that is to say, under conditions in which a bird makes a vertical gain of height when wind facing. The wind canting occurs at the end of such gain of height.

WIND FACING.—A bird is said to be wind facing when, in a wind, it remains gliding to and fro turning alternately off the wind to one side or the other and thus avoids travelling far from its mean position over the earth.

WING-TIP.—See "Wing Structure."

WING SECTIONS.—Imagine a bird gliding horizontally with wings extended. If a wing section is then made in a fore and aft direction, this section has been made at right angles to the long axis of the wing. The anterior margin of the wing is at one end of the section thus obtained. The wing sections described in the text are of this nature. Wing sections of three types have been described. First, "**STRIGINE**," the type found in owls and herons, in which the wing section is very thin, and whose possessors appear to have a good gliding angle. Second, "**AQUILINE**," found in most eagles and buzzards. The leading edge is rounded and thickened. The underside is smooth. Third, "**VULTURINE**," characterised by the presence of large ridges transverse to the line of flight. This type is met with in the heavier and more efficient soaring birds, birds which do not appear to have a good gliding angle in unsoarable air. The method of making wing sections of birds' wings has been described in the text. Wing sections of the wings of dragon-flies are best made by embedding the wing in a block of plaster of Paris. After two or three days the block may be rubbed on a coarse file until the desired wing section is exposed. After the filing the wing section becomes visible as a fine black line on washing the cut face of the block in water.

WING STRUCTURE.—The bones of the wing are separated by the shoulder, elbow, wrist or carpal, and knuckle or metacarpal joints. The outer part of the wing or "wing-tip" can be rotated slightly round the two last-named joints. On the inner side of the carpal joint are the arm bones, namely, the humerus, radius, and ulna. On the outer side of the carpal joint are the fused metacarpal bones and the "phalanges," which are vestiges of three fingers. The vestige of the first digit is the "alula." This is a small bone often furnished with a claw and bearing a tuft of stiff feathers. It lies along the anterior margin of the wing. In the larger birds the alula can be advanced or retired and also rotated upwards or downwards. The chief feathers of the wing which form the greater part of the supporting surface during flight are known as "quills." Of these the bases of the

outer four are fused with the bones of digits II. and III. forming the "DIGITAL QUILL MASS." This mass can be rotated as a whole at the knuckle joint. The rotation is of slight extent and is to and fro round the long axis of the wing. Slight flexing can also occur at this joint. That is to say, if the wing is extended horizontally the outer end of the digital quill mass can be moved forwards or backwards in the horizontal plane. These four quills as they are attached to the finger bones or phalanges are known as the "DIGITAL QUILLS." The immediately succeeding quills, generally six in number, are attached to the metacarpal bone, forming the "METACARPAL QUILL MASS." These quills are known as the "METACARPAL QUILLS." The digital and metacarpal quills together are known as the "PRIMARY QUILLS." The primary quills are followed by a series of quills attached to the ulna and known as the "SECONDARY QUILLS" or "SECONDARIES." The innermost quills of smaller size and of small number correspond in position to the humerus, and are known as "TERTIARIES." The digital quill mass and the metacarpal quill mass together form the "WING-TIP." The bases of the quills and the leading edge of the wing are covered with numerous small feathers known as "COVERTS" or "COVERT FEATHERS." The anterior margin of the wing is rounded off and thickened by numerous minute feathers known as "DOWN" which lie under the covert feathers.

APPENDIX II.

TABLE FOR CONVERSION OF METRES PER SECOND INTO
MILES PER HOUR.

Metres per second.	Miles per hour.	Metres per second.	Miles per hour.	Metres per second.	Miles per hour.
1 ..	2.237	7 ..	15.65	25 ..	55.92
2 ..	4.47	8 ..	17.89	30 ..	67.11
3 ..	6.71	9 ..	20.13	35 ..	78.29
4 ..	8.94	10 ..	22.37	40 ..	89.48
5 ..	11.18	15 ..	33.55	45 ..	100.66
6 ..	13.42	20 ..	44.74	50 ..	111.85

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